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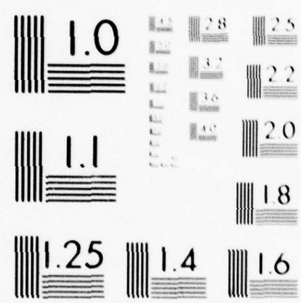

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMATION AND COMMUNICATION

by

M. I. Vitenberg

FOREIGN TECHNOLOGY DIVISION

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMATION AND COMMUNICATION

By. M. I. Vitenberg

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PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere. When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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Part Two.

PART TWO.

POLARIZED. Magnitoelectric and high-frequency relays.

POLARIZED. MAGNITOELECTRIC AND HIGH-FREQUENCY RELAYS.

Chapter Thirteen

POLAR RELAY.

13-1. General information.

The electromagnetic polar relays possess high sensitivity, high control ratio (amplification), by high speed of response, by high output factor, by small distortion of momentum/impulse/pulses, by the directivity of action (armature travel depends on direction of flow in windings) and they can be used for the work with both the currents of two directions and by the current of one direction. The widest application polar relays were obtained in radio-electronic equipment, equipment for automation,

telemechanics and electrical communication. But they are applied also in many other equipment/devices as, for example, for commutation, amplification, pulsing, stepless control of reversible motors and for many other operations.

Polar relays differ from those who were not polarized (neutral) in the fact that they have two of independent of each other magnetic of the flow: the polarizing and worker (or governing).

The polarizing magnetic flux is created usually by the permanent magnets (in some special cases instead of the permanent magnets they are applied electromagnets).

The working (governing) magnetic flux is created by windings, over which occur/flow/lasts the operating current. Value and direction of flow depend on the state of the circuit in which are included these windings.

In the absence of working coil current of relay on armature, operate thrusts, created by the flows of the permanent magnet (Fig. 13-1).

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The magnetic flux Φ_0 of the permanent magnet, passing through the armature of relay, branches on two parts: the flow Φ_1, passing through in left gap δ_1, and the flow Φ_2, which passes in right gap δ_2.

In the presence only of these two flows, the armature of relay is arrange/located to the right or to the left of neutral (average) position. In free position (i.e. when $\delta_1 = \delta_2$) the armature is not stopped due to the instability of this position.

After the connection/inclusion of coils I and II appears the supplementary M.M.F., which creates the working (governing) flow Φ_y, which passes consecutively through both gaps.

Let us assume that the armature is located at left contact KP, then in left gap will operate the net flux $\Phi_1' = \Phi_1 - \Phi_y$, and in right gap $\Phi_2' = \Phi_2 + \Phi_y$.

At the specific value of coil current of relay, equal to spill current, the attracting force, caused by flow Φ_2',

will be more than the force, created by flow Φ_1, and the armature of relay will move from left to right.

Polar relay can be controlled neutrally or with fpredominance to one of the contacts.

Neutral is called such adjustment during which the armature of relay is moved of one contact to another with the identical current strength. In the absence of coil current, the armature of relay remains at the contact to which it was moved. Neutral adjustment is achieved by the symmetrical location of contacts with respect to neutral line. This adjustment, furthermore, it is called still two-position.

During adjustment with complete predominance, the armature of relay after the disconnection of coil current always returns to the contact of rest KP. Relay also can be controlled with partial predominance. In this case, just as during neutral adjustment, armature of relay in the absence of coil current can be located at any contact. But the value of spill current at the overbanking of the armature of relay from contact KP to contact KR will be more (or less) than at the overbanking of armature in opposite direction.

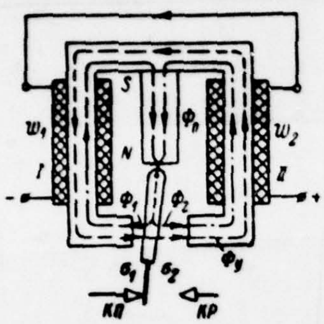

Fig. 13-1. The outline of magnetic value of polarized relay.

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If the armature of relay spring-mounted, then with insufficient constant value of magnetic flux armature will remain in the mid-position in the absence of coil current and will not concern contacts. This adjustment of relay is called three-position.

The conventional designations of polar relays with one, two and three windings, accepted in telegraphy, are shown to Fig. 13-2a, b, c. In the circuits of telephony and automation, the polar relays frequently are designated

otherwise; examples of the designations of a neutral two-position relay (of type RP-4) with one winding, three-position relay (of type RP-5) with two windings and a two-position relay (of type RP-7) with predominance and with three windings are shown to Fig. 13-2d, e, f.

Leading-out plugs from the left and right of the contacts of relay of the type RP are designated respectively letters L and P, leading-out plug from armature am designated in letter Ya. Upon the connection/inclusion of plus of battery at the beginning of winding, and minus - toward the end of the armature winding of relay is closed with right contact. In the absence of coil current, the armature of relay of type RP-7 always concerns right contact.

13-2. Classification of polar relays.

Polar relays can be classed according to the circuit of magnetic circuit and according to the construction of the reed of armature.

According to the circuit of magnetic circuit, the polar relays are divided into three groups: with consecutive magnetic circuit (Fig. 13-3a), with parallel or differential magnetic circuit (Fig. 13-3b, c) and with bridge magnetic circuit (Fig. 13-3d, e, ..., h).

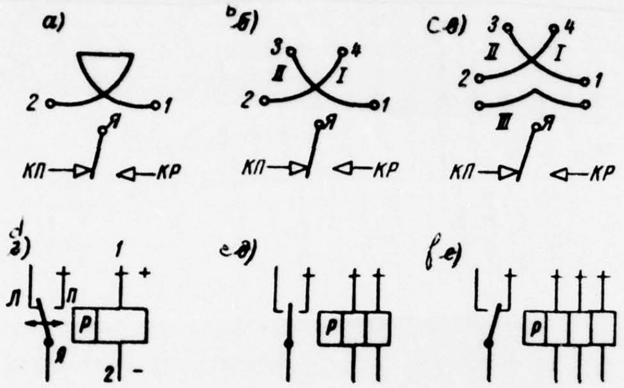

Fig. 13-2. The conventional designations of polar relays in the circuits: a, b, c) in telegraph circuits; d, e, f) in telephone circuits.

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In series circuit of magnetic circuit, the polarizing magnetic flux of the permanent magnet and the governing (alternating/variable) magnetic flux, created by windings, pass along one common circuit.

In relay with differential circuit of magnetic circuit, the flow from the permanent magnet, passing through

armature, branches on two opposite paths to cores 1 and 2, and on armature operates a difference in these flows. Alternating/variable magnetic flux is not virtually branch/shunted into the circuit of magnet, since the resistor/resistance of this path is great in comparison with the resistor/resistance of the circuit of cores.

Relays with bridge circuit of magnetic circuit are divided into two subgroups: with the common/general/total (undivided) and divided paths of the polarizing and manager magnetic fluxes (with four and two working air gaps).

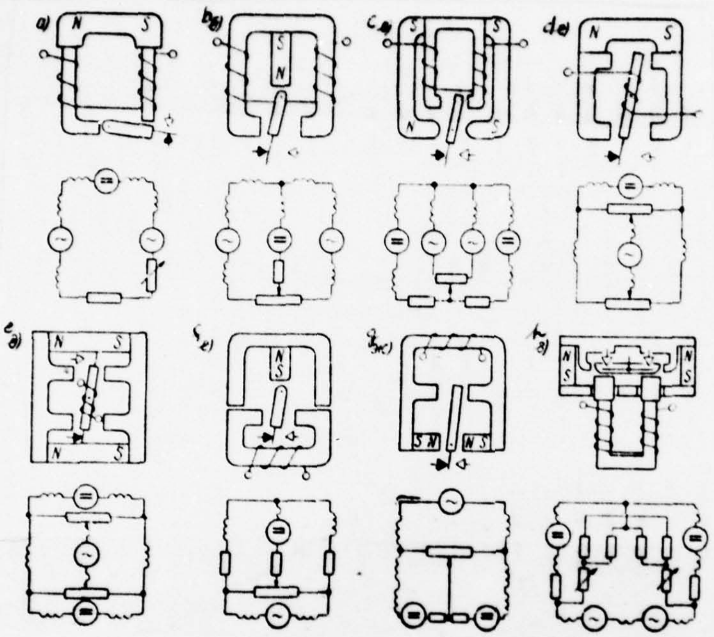

Fig. 13-3. Circuits of the magnetic circuits of the polar relays: a) consecutive; b, c) parallel or differential; d, e) bridge with the common/general/total paths of the polarizing and manager of flows; f, g) bridge with the divided paths of the polarizing and manager of flows; h) dual bridge with the divided paths of the polarizing and manager of flows.

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In bridge circuit of the first subgroup (Fig. 13-3d, e) the polarizing magnetic flux is directed along the framework of magnetic circuit with the pole pieces and across armature; however, the part of the polarizing flux is branch/shunted and passes also along armature, but governing flow is directed along armature and framework. In the circuit of the second subgroup (Fig. 13-3f, g) the polarizing and governing flows pass along different paths. The polarizing flux is directed along the upper half of armature, and governing - across the lower part of the armature and along core with the pole pieces.

To Fig. 13-3h, is shown the diagram of the dual bridge of the magnetic system of relay of the type RPS. In it the paths of the polarizing and governing flows are divided. The polarizing fluxes pass across the end/leads of the armature, and manager - along armature and cores of relay.

A considerable decrease in section and weight of armature (without the danger of its saturation) is possible only when the polarizing flux is directed not lengthwise, but it is perpendicular to the plane of armature.

In the equivalent circuits of magnetic circuits on Fig. 13-3, sources of constant and alternating/variable magnetizing force are designated in small circles, gap reluctance - by the signs of effective resistance and the reluctances of the ferromagnetic sections of the magnetic circuit of relay - by the signs of inductance.

By the construction of contact system, the polar relays are divided: 1) on relay with the flexible contact stud of armature and the rigid fastening of fixed contacts (Fig. 13-4a, b), 2) on relay with the rigid contact stud of armature and with the rigid fastening of fixed contacts even 3) on relay with the rigid contact stud of armature and with the flexible attachment of fixed contacts (Fig. 13-4c).

Flexible contact stud (Fig. 13-4a) consists of two flat/plane bronze springs 1 with contacts 2, strengthened to the end/lead of armature 3. The free end/leads of these springs are bent and press to each other from a by effort/force.

With the impacts of slide contacts against motionless springs, they are bent and their end/leads with friction

are moved relative to each other, in consequence of which the large part of the kinetic kinetic energy of armature it is absorbed with friction of these springs.

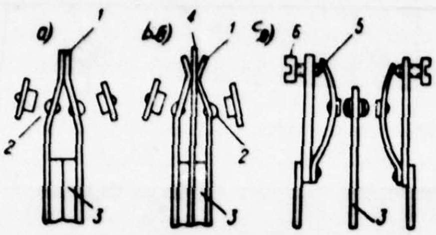

Fig. 13-4. Contact systems of the polar relays: a) armature with flexible reed of two springs; b) armature with flexible reed of three springs; c) armature with rigid reed and the flexible attachment of fixed contacts.

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For stabilization in the time of the coefficient of friction between two contact springs 1, sometimes is placed third fine/thinner spring 4 (Fig. 13-4b) whose surface is covered with the thin layer of silver.

Of relay with rigid reed and the flexible attachment of fixed contacts (Fig. 13-4c) the kinetic energy of armature is absorbed with friction of the end/leads of springs 5 against supporting screw/propellers 6, pressure on

which can be regulated to disappearance fragment in contacts.

Flexible contact stud absorbs the vibration of armature, decreases the time of losses and increases the output factor of relay.

13-3. The polar relays of types RP and of RPB.

The miniature/small polar relays of the type RP are manufactured in four modifications: RP-3, RP-4, RP-5, and RP-7 (Fig. 13-5). These relays have high sensitivity and are applied in equipment for automation, in the receiving and transmitting circuits of equipment for tone telegraph and in many other cases.

Relays of the type RP are intended for operation in mobile units during changes in the ambient temperature from -40 to +50°C, relative humidity to 98o/o at temperature of 20 ± 5°C, vibration with frequency 50 Hz during acceleration to 5 g.

The magnetic relay circuit of types RP and of RPB is constructed according to bridge circuit Fig. 13-3f in which the path of constant and governing (alternating/variable) of magnetic fluxes are divided. Governing magnetic flux is directed across armature.

The permanent magnet of L-shape made of an aluminum-nickel steel together with the pole piece (shoe) made of mild transformer steel of brand EA is flooded into the silumin base of relay.

Section of magnet 7.2 x 17.2 mm, length 23 mm.

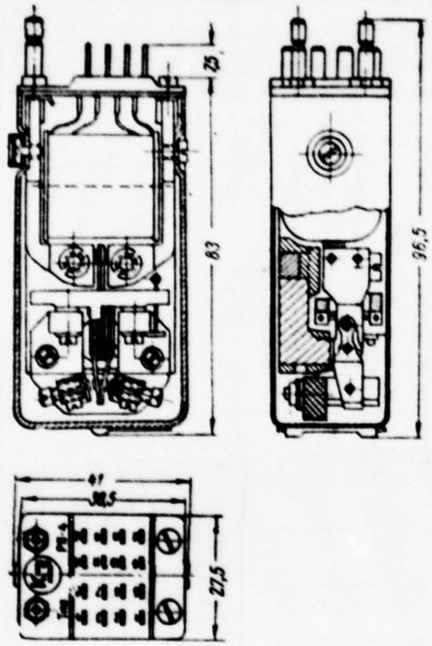

Fig. 13-5. Miniature/small polar relay of the type RP.

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To cap two screw/propellers screwed on the magnetic circuit in the form of the extended rectangle, assembled from sheet molybdenum Permalloy by thickness 1 mm; the section of the core of magnetic circuit 3.8 x 4 mm, average length its 90 mm.

On core is arrange/located the coil from black monolith on which it is coiled from one to seven windings. Length of the winding space of coil 24.8 mm, height 8.1 mm. Inner diameter of the winding 7.4 mm. Equivalent resistance of one turn of the winding $10.9 \cdot 10^{-6}$ by ohm (k_3 = 0.39). Section of the packet of the pole pieces 9.5 x 10 mm.

The armature of the relay is riveted of two plates of mild transformer steel by section 1 x 7 mm is fastened (it is suspend/hung) on fine/thin steel spring within the silumin framework. The thickness of spring depends on the mode of the adjustment of relay and is within the limits from 0.15 to 0.28 mm. The width of spring is equal to 0.8 mm and length its not 1.5 mm from each side. For the stabilization of the position of armature, suspension spring is stretched with force of approximately 7 kgf. To armature are riveted two contact springs from a tin-phosphorous bronze by thickness 0.20 mm with contacts from alloy PlI-10. For absorbing the kinetic kinetic energy of armature by friction the end/leads of springs 1 are bent and press to each other with force 21-26 g (Fig. 13-4). Frictional area of these springs of approximately 2 x 5 mm. Armature

and the contact system of relay are assembled on separate ceramic base. The silumin framework with armature is screwed on by two screw/propellers to the base from ceramics, at other end/lead of which are fastened two contact are stable with motionless contact springs and the adjusting screws.

Contacts have spherical contact surface. Distance between the contacts 0.08 mm. Air gap between magnet and armature 0.3 mm, the gap between pole pieces and armature 2 x 0.45 mm.

The end/leads of windings and circuit of contact system are soldered to 16 flat/plane tags (commutator bars) of special plug from phenoplast. This block is attached by two screw/propellers and two guide pins to silumin base (housing).

For the inclusion of relay into circuit, is applied special coupling block to 16 sockets.

As the relays of types RP-3 and RP-4 two-position, they have neutral adjustment with the magnetic blocking of armature. Contacts are establish/installed symmetrically relative to neutral. With the disconnection of armature

current, of relay is held at that pole to which it was pullled.

A relay of type RP-3 is characterized by from relay of type RP-4 smaller sensitivity (3-8 ampere-turns), by large pressure in contacts in the absence of coil current (3-7 g) because of a fine/thinner suspension spring of armature (0.15 mm).

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Relays of type RP-5, three-position polarized. The armature of relay in the absence of excitation is located in the mid-position and clear contacts.

The construction of all these three modifications of relay is identical, but a relay of type RP-5 is characterized by from relay of type RP-4 larger thickness of the suspension spring of armature (0.28 mm instead of 0.23 mm).

A relay of type RP-7 is the two-position polar relay with predominance. Both contacts are arrange/located along one side from neutral. In the absence of coil current, the

armature of relay of type ~~rp~~ RP-7 is always pressed to right contact.

Relays are shielded from dust and the mechanical damages by detachable aluminum jackets.

Overall dimensions 27.5 x 41 x 96.5 mm, weight with jacket of approximately 170 g.

The fundamental parameters of relay of type RP-4, RP-5 and RP-7 are given in table 13-1.

relay of the type RPB (non-ceramic) differ from relay of the type RP in the fundamental the fact that do not have the ceramic base. They also are manufactured in three analogous modifications: ~~rpb~~ RPB-4, ~~rpb~~ RPB-5 and ~~rpb~~ RPB-7. The silumin framework with armature and the struts with the motionless contact springs of the relay of the type RPB are fastened on the flanges (boss/inflows) of silumin base and are isolate/insulated from the latter by plugs from plastic (K214-2) and by washers from fiberglass laminate.

According to the data of the windings, sensitivity and other parameters of relay of the type RPB are approximately

identical the relay of the type RP.

13-4. A polar relay of the type RPS.

The miniature/small polar relays of the type RPS are manufactured in three modifications: ~~rps~~ RPS-4, ~~rps~~ RPS-5, RPS-7 (Fig. 13-6), have increased sensitivity and stability Rand are applied in equipment for automation.

Relays are intended for operation in mobile units during changes in the ambient temperature from -60 to +70°C, relative humidity to 98o/o at temperature of 30 ± 10°C, vibration with frequency from 20 to 100 Hz and acceleration to 4 g, vibration with frequency from 100 to 200 Hz upon acceleration to 2.5 g, centrifugal accelerations to 25 g and at atmospheric pressure to 5 mm Hg. The magnetic relay circuit of the type RPS is constructed according to the circuit of dual bridge. For obtaining the linear thrust characteristics, basic part of the polarizing fluxes passes through the turnings of the pole pieces ("grapplers") into the end/faces of armature.

The magnetic system of relay of the type RPS consists of the upper and lower massive bases of circular shape of steel of brand E by diameter 30 mm by thickness with respect 4 and 6 mm between which are jammed two permanent magnets by section 8.5 x 16 mm by length 10.5 mm from alloy anko-2.

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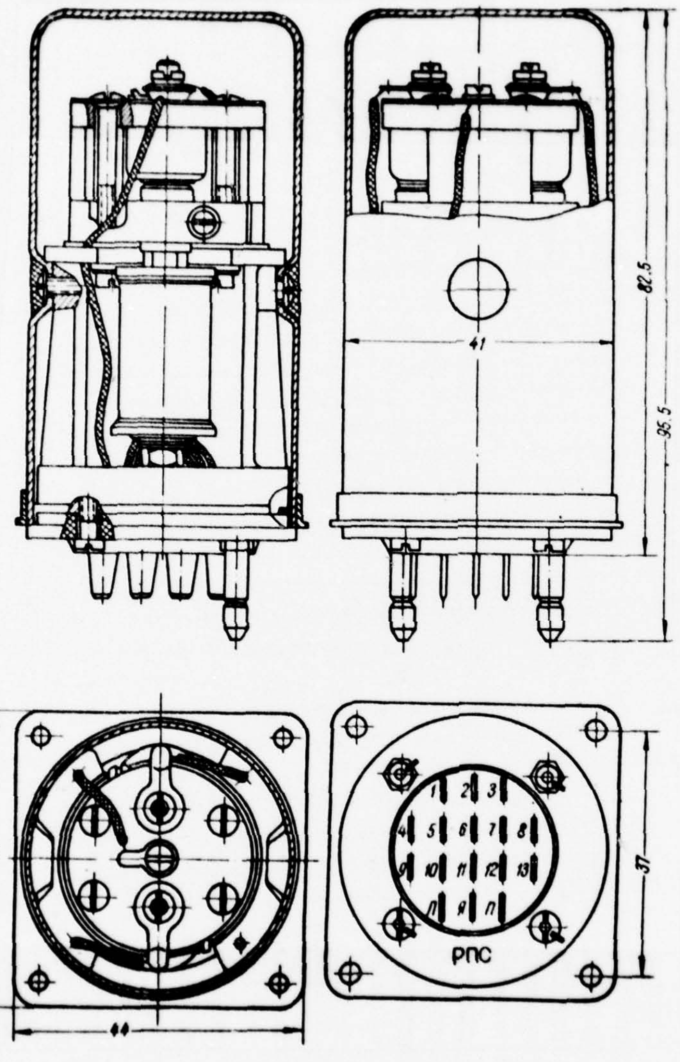

Fig. 13-6. A polar relay of the type RPS.

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Magnets are tightened four by screw/propellers (MZ) made of the stainless steel (1Kh18N9T), covered into lower base. The face of magnets is ground in circumference, the weight of magnet 7 g.

In upper base are pressed two pole pieces of cylindrical form by diameter 12.5 mm made of steel A12 with semicircular projecting turnings ("grapplers") at end/leads.

In shoes are drilled the open-end holes of conical shape by diameter 4.2/6 mm into which are pressed brass screwed sleeves for adjusting screws (Ø3 x 16 mm). Plugs are isolate/insulated from caps by separators and washers of mica by thickness 0.045 mm and glass tape (0.1 mm), saturated with cement ~~bf~~ BF-2. In the end/lead of the adjusting screw, are pressed "motionless" area contact by diameter 2.2 mm by height 0.6 mm from platinum fusion with rhodium (10o/o). Upper end of the adjusting screw has screwdriver slot and lock nut for the attachment of screw/propeller after gap adjustment. In lower base against pole pieces of caps, are sealed in two bronze plugs (by

diameter 9.1/6.5 mm) with the thread into which are covered the poles of the cores, prepared from the alloy of 80NKhS. Base has two gashes, passing through plugs. After the adjustment of air gap, the poles of cores are plug/stopped by two auxiliary screw/propellers, covered into the end/face of base. the diameter of cores 4 mm the diameter of pole along thread 8 mm. Between the pole and the core, there is a hexahedron for the rotation of core during gap adjustment between pole and armature.

To the free end/leads of the cores, are put on the coils with framework/bodies from plastic (K-214-2) and windings. The magnetic circuit of cores is closed by two cross connections (plates) from Permalloy (0.5 mm), that press coils with aid of two nuts. Inner diameter of the winding 5.6 mm, the height/altitude of winding/coil 4.5 (5.2) mm and length 21.4 mm. Equivalent resistance of one turn of the winding $7.45 \cdot 10^{-6}$ by ohm with $k_3 = 0.39$. Value $C_m = 2{,}9 \cdot 10^{-6}$ ohm.

Armature consists of two plates, stamped of sheet Permalloy of the brand of N79M4 by thickness 0.5 mm. The end/leads of the plates are cut off in circumference; of lower armature plate the end/leads are bent upwards and

encompass the end/faces of upper armature plate. In upper armature plate against the adjusting screws with fixed contacts, there are two opening/apertures through which project/emerge the slide contacts, riveted to the contact spring of armature.

Between armature plates are arrange/located contact spring from bronze BrB2tv with thickness 0.15 mm with two contacts on end/leads, the spring spring from the same bronze and the suspension spring on which the armature is suspended to bracket.

The suspension spring of the armature of relay of type RPS ~~rps~~-5 has width 0.8 mm and working length 2 x 2.8 mm, it is made from bronze BrB2tv with a thickness 0.3 mm. All these springs after production pass heat treatment.

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Armature plates and the locating between them springs are tightened in middle by two hollow rivets and stainless steel. Weight of armature 1.5 g. Diameter of the slide contacts 1.8 mm, height 1.2 mm a radius of working surface 2 mm. Distance between the contacts 2 x 0.08 mm.

The end/leads of the suspension spring of armature are riveted to the bracket from bronze BrB2 which with the aid of screw/propeller and two pins is attached on the upper base of relay. The slide contacts of relay have connection with magnetic system, but magnetic system is isolate/insulated from support by separator of getinax by thickness 0.5 mm, and the fastening screw/propellers - by textolite plugs.

A relay of type RPS-5 is three-position. Air pole gap of core and armature 2 x 0.4 mm, radial clearance between faces of lower armature plate and the turnings of the pole pieces 2 x 0.15 mm.

As relays of type RPS ~~rps~~-4 two-position, it has neutral adjustment. In connection with the fact that the spring spring of armature is unavailable for regulation, the contacts of relay of type RPS ~~rps~~-4 have sufficiently considerable vibration.

A relay of type RPS-7 is two-position relay with predominance.

In the absence of coil current, the armature of relay of type ~~rps~~ RPS-7 is always pressed to right contact.

The construction of all three modifications of relay is identical, the relay of types RPS-4 and RPS-7 is characterized by from relay of type RPS-5 smaller thickness of the suspension spring of armature (0.2 mm instead of 0.3 mm).

The magnetic system of relay is screwed on by two screw/propellers to the cast strut (bracket) from aluminum alloy ruby-colored-2. To the base of strut, is attached cut-in sixteen-contact plug from plastic of circular shape.

Relay is shielded by a jacket-screen of cylindrical form made of steel EA with thickness 0.5 mm. Jacket is fastened to strut with two screw/propellers. Jacket flanged of square form with four openings for fastening relay on the corners. Between the jacket and the receptacle laid packing ring from the thelastomer GE-N - 301 of circular section as diameter 2.5 mm. Jacket is painted by the color of gray color.

Overall dimensions of relay 44 x 44 x 95.5 mm. Weight with jacket 200 g, without jacket 145 g.

13-5. A polar relay of the type PS11.

The miniature/small polar relays of the type RPS11 (Fig. 13-7) have smaller overall dimensions and weight, than relay of the type RP are manufactured respectively in four modifications: RPS11/3, RPS11/4, RPS11/5 and RPS11/7.

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Relays of the type RPS11 are intended for operation during changes in the temperature from -40 to +50°C, relative air humidity to 98o/o at temperature of +20°C, vibration in the range of frequencies from 15 to 55 Hz with acceleration 1.5-3 g and linear accelerations to 5 g.

Relay maintain/withstands vibration test in the range of frequencies from 30 to 45 Hz by acceleration to 6 g and

from 40 to 70 Hz with acceleration to 4 g, and also testing for impact strength during acceleration to 50 g (2000 impacts).

The magnetic system of relay of the type RPS11 is analogous to the magnetic system of relay of the type RP, but armature has another construction of suspension.

Armature is welded to the flat/plane suspension spring, working to curvature and attached by one end/lead on silumin strut.

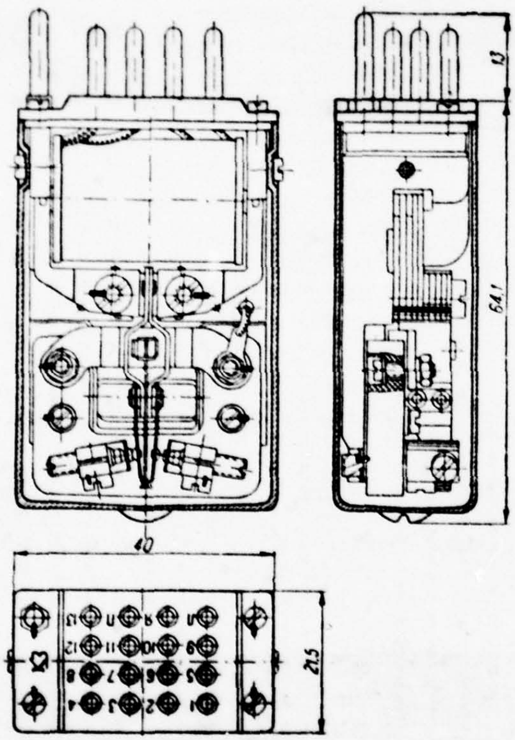

Fig. 13-7. Polar relays of the type RPS11.

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Between two contact springs is arrange/located the third fine/thin silver-plated spring (Fig. 13-4b), that ensures the stable coefficient of friction between the end/leads of

contact springs and, therefore, the absence of shaking of contacts. The base from ceramics on which are fastened the fixed contacts, has simpler form, than in relay of the type RP. Relay is equipped by plastic cut-in block with sixteen tags and shielded detachable aluminum jacket.

Overall dimensions of relay 21.5 x 40 x 64.1 (77.1) mm, weight 100-125 g. Relay can have to seven windings.

The ampere-turns of the function of relay of the type RPS11/3 are equal to 4-10 ampere-turns the type of RPS11/4 are equal to 1-4 ampere-turns the type of RPS11/5 are equal to 1-4 ampere-turns and the type of RPS11/7 are equal to 4-10 ampere-turns.

The power of the function of relay of the type "RPS11/4 "and RPS11/5 is equal to 0.01-0.16 mW, relay of the type RPS11/3 and RPS11/7 it is equal to 0.16-1.04 mW.

Pressure in the circuit closing contact of relay of the type RPS11/7 is not less than 2 g, in breaking 4 g. Gap between contacts 0.06-0.08 mm.

The service life of the contacts of relay of the type RPS11/4 with load 0.05 A - 120 V and the relay of types RPS11/5 and RPS11/7 with load 0.2 A are 27 V is not less than 10^7 functions.

13-6. A polar relay of the type RPS18.

The miniature/small polar relays of the type RPS18 (Fig. 13-8) are characterized by considerably larger vibration resistance and smaller overall dimensions than the relay of types RP, of RPS and RPS11. They are manufactured also in three modifications: RPS18/4, RPS18/5 and RPS18/7.

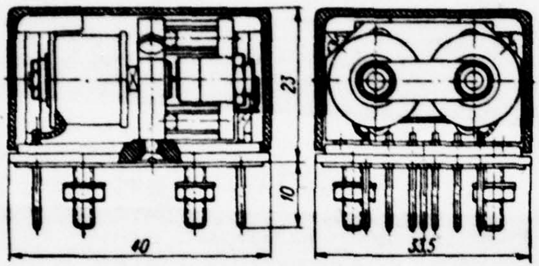

Fig. 13-8. A polar relay of the type RPS18.

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Relays of the type RPS18 are intended for operation at ambient temperature from -50 to +80°C, relative air humidity to 95o/o at temperature of 20°C, atmospheric pressure to 5 mm Hg, with vibration in the range hour of from 20 to 50 Hz with amplitude 1 mm and from 50 to 600 Hz with acceleration 2.5 g (RPS18/5 is 10 g) and linear accelerations to 20 g.

The resonance frequency of the movable system of relay of the type RPS18/5 is within the limits from 1100 to 1400 Hz, and relay of the type RPS18/7 - within limits 320-360 Hz and 900-1100 Hz, but at these frequencies of

relay, they do not auto/self-wear/operate during acceleration 10 g.

A relay of the type RPS18 has a circuit of magnetic circuit, analogous to relay of the type RPS.

Armature consists of the thin plate of Permalloy with the bent back at right angles edges and cross-shaped spring of beryllium bronze which simultaneously serves as the contact and suspension spring, working for twisting. Is establish/installed armature on support, attached on the upper base on which are arrange/located two plugs with the fixed contacts, isolate/insulated by glass.

Relay is mounted on plastic board with nine times leading-out plugs and two bolts for attachment and shielded detachable jacket from plastic. It can have to three independent windings.

The power of the function of relay of the type RPS18/4 upon connection/inclusion of one of the two windings is within the limits from 0.4 to 1.6 mW (4-8 ampere-turns), relay of the type RPS18/5 - from 0.9 to 4.9 mW (6-14 ampere-turns) and a relay of the type RPS18/7 - from 0.9 to 8.1 mW (6-18 ampere-turns).

The service life of the contacts of relay with resistive load 0.25 A - 30 V is not less $5 \cdot 10^5$ functions, and with inductive load 0.4 A - 30 V are not less than 10^3 functions. Insulation resistance is more than 100 MΩ, with the increased humidity it is not less than 10 MΩ. The testing voltage of insulation 500 V eff., between dead contacts - 350 V eff.

Overall dimensions 33.5 x 40 x 23.3 (33) mm, weight 65-80 g.

13-7. Miniature polarized relay of the type RPS20.

The miniature airtight polar relay (the remote-control switch) with two stud switches of the type RPS20 (Fig. 13-9) is manufactured only with two-position adjustment (with the magnetic blocking of armature in its end positions).

Relay is intended for operation at ambient temperatures from -60 to +60°C, relative humidity to 98o/o at +20°C,

atmospheric pressure from 5 to 760 mm Hg, vibration in the range of frequencies from 5 to 50 Hz with amplitude 1 mm, from 50 to 600 Hz with acceleration 12 g and from 600 to 2000 Hz with acceleration 10 g with linear accelerations to 25 g, and impacts with acceleration to 100 g.

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Relay has the differential polarized two-coil magnetic system with flat/plane symmetrical armature. Magnet is arrange/located between coils. Foundation (base) has oval form and it is made from sheet Kovar alloy.

Contact system consists of two stud switches and it is mounted on the basis of relay. The fixed contacts are soldered to the internal end/leads of the leading-out pins from Kovar alloy, isolate/insulated from foundation by glass insulating beads. Movable contacts are pressed into the flat/plane contact springs, soldered also to leading-out pins. For the transmission of effort/force to movable springs, the armature is equipped by two glass beads.

Relays shielded seamless brass brow, which after assembly and adjustment of relay is soldered to foundation.

Relay has two independent windings. Power, necessary for the function (overbanking) of armature upon connection/inclusion of one of the windings, are equal to 0.4-0.6 W (two series-connected windings 0.2-0.3 W). The service life of contacts with the resistive load of 2 A - 32 V or 3A -20 V is not less than 10* functions. The time of triggering of relay with nominal voltage is not more than 10 ms.

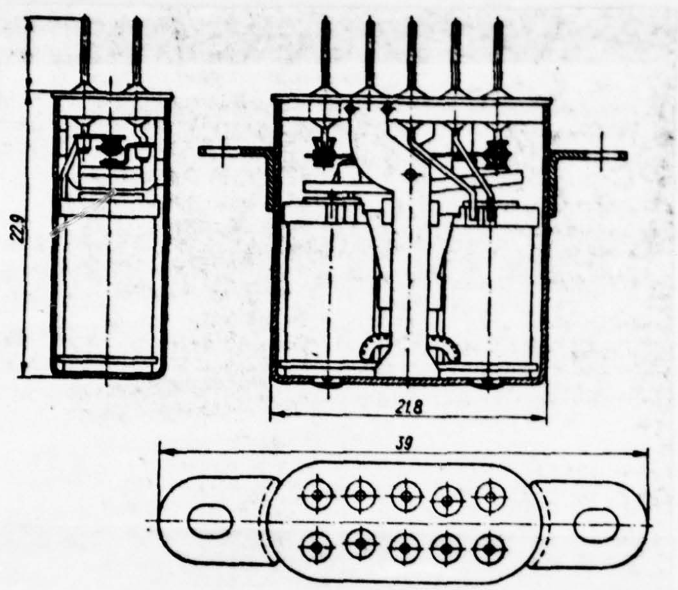

Fig. 13-9. Polar relay of type RPS20.

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The insulation resistance of relay is more than 100 MΩ; after the stay under conditions of the increased humidity it is not less than 10 MΩ.

The testing voltage of insulation 500 V eff. The overall dimensions of relay 9.7 x 21.8 x 22.9 (28.9) mm; weight is not more than 20 g.

13-8. Polarized remote-control switch of the type DP-12.

The miniature/small airtight polarized remote-control switch with twelve stud switches of the type DP-12 (Fig. 13-10) has two-position regulation (with the magnetic blocking of armature).

Switch is intended for operation at temperatures from -60 to +80°C, relative humidity to 98c/o at 40°C, atmospheric pressure from 5 to 760 mm Hg, vibration in the range of frequencies from 20 to 50 Hz with amplitude 1 mm and from 50 to 1500 Hz with acceleration 10 g, linear accelerations to 25g and impacts with acceleration 75 g (impact strength to 150 g).

The magnetic system of switch consists of steel framework, four cores with coils, flat/plane magnet (arrange/located between them) and the common/general/total symmetrical armature of rectangular form.

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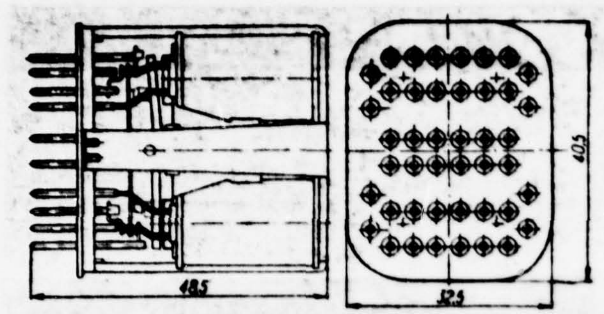

Fig. 13-10. Remote-control switch of type DP-12.

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Normally armature is pullled to one pole pair (cores), after the supply of the short-term current pulse of opposite direction in the second armature winding is moved to another end position (to another pole pair) and it changes over all contacts.

Switch is shielded by the brass jacket which after assembly and adjustment of contact system is soldered to foundation. Switch has 4 windings by resistor/resistance on 420 ohm each. Actuation voltage on each of the windings 19 V, the voltage of failure 10 V.

The power, necessary for the function of switch with the aid of one of the four windings, is equal to 0.70-0.86 W.

The service life of contacts with the resistive load 2 A - 32 V of direct current or 1 A - 115 V of alternating current by frequency 400 Hz is not less than 10^{4} functions, with the load 10 A - 32 V it is not less than 100 closing/shortings. Triggering time is not more than 12 ms. Insulation resistance is more than 100 MΩ. The testing voltage of insulation 500 V eff.

The overall dimensions of switch 34 x 40 x 41 (48.5) mm, weight are not more than 220 g.

13-9. Polarized local relay of the type TRM.

A polar relay of the type TRM (Fig. 13-11) is applied in equipment for automation, and also in telegraph circuits as the transmitting and local relay.

Relays of the type TRM are intended for operation during changes in the ambient temperature from 0 to +50°C and relative humidity to 95o/o at temperature of 20 ± 10°C. Relays maintain/withstand vibration with frequency 10-70 Hz during accelerations respectively (5-3) g during 30 min and agitation with impact acceleration to 75 g.

The magnetic relay circuit of the type TRM is constructed according to differential circuit and consists of two cores with coils, two permanent magnets and the armature, which rotates on the axis between magnet poles and cores.

The circuit of the magnetic relay circuit of the type TRM is given in Fig. 13-3c, path of constant and the manager of flows in cores are not divided.

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In the middle of armature, is attached the steel polished axis, which rotates in the bronze plugs, pressed in the housing of relay. The center of gravity of armature

coincides with the rotational axis, arrange/located between the poles of the permanent magnets.

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Magnets have U-shape form and are made made of band chromic magnet steel of the brand of YeKhZ. The section of each magnet 3 x 8 mm, length is about 90 mm.

Relay is mounted on silumin foundation, it is equipped by plug with eight by leading-out "banana" receptacles and it is shielded by jacket from plastic.

On each coil of relay of the type TRM, are wound two windings on 2300 turns from wire by diameter 0.13 mm of the brand PEL. Resistor/resistance of the first winding to direct current 85 ohm, second 130 ohm.

Upon the series connection of windings, the first winding of one coil is connected with the second winding of another, and vice versa, forming two windings of relay.

Length of the winding space of each coil 29 mm, height 5.5 mm; the inner diameter of the winding 7 mm. Averaged resistor/resistance of one turn of winding 5.5×10^{-6} ohm with $k_3 = 0.39$. Value $C_m = 2{,}15 \cdot 10^{-6}$ ohm.

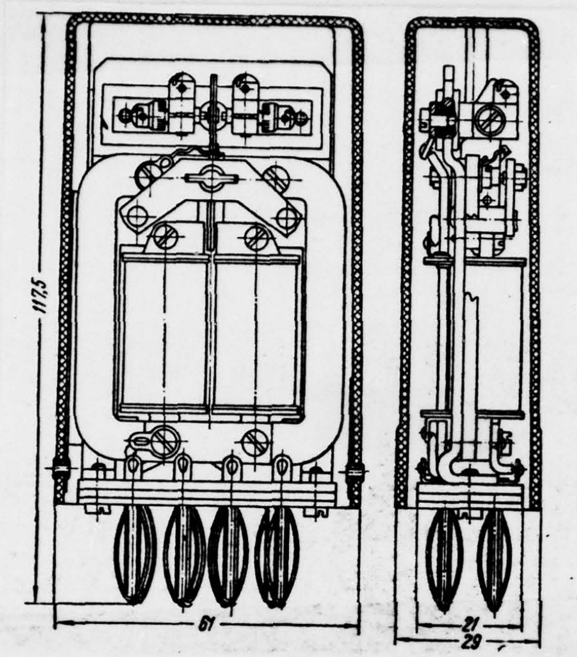

Fig. 13-11. Polarized local relay of type TRM.

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Table 13-1. Fundamental characteristics of polar relays.

(1) Характеристики	(2) Единица измерения	(3) Тип реле										
		РП-3	РП-4	РП-5	РП-7	РПС-4	РПС-5	РПС11/4	РПС11/5	РПС18/4	РПС18/5	ТРМ
(4) Чувствительность реле (статическая)	(5) ав	3—8	1,5—4	1,5—4	4—10	2—5	1—3	1—4	1—4	4—8	6—14	22—28
(6) То же	(7) мвт	0,09—0,64	0,02—0,16	0,02—0,16	0,16—1,0	0,03—0,18	0,007—0,066	0,01—0,16	0,01—0,16	0,4—1,6	1—5	2,7—4,5
Ампер-витки отпускания (8)	(5) ав	—	—	—	1,2—5	—	—	—	—	—	—	—
Номинальное возбуждение (10)	(5) ав	40	10	10	20	10	10	10	10	—	—	90
Зазор между контактами (11)	мм	< 0,1	0,06—0,12	2(0,08—0,15)	0,07—0,1	—	2 × 0,08	0,06—0,08	2 × 0,08	—	—	0,10
Контактное давление при $AW = 0$ (12)	(16) г	3—7	1,3—5	—	6—10	1,5—2	—	1—2	—	—	—	6—14
Контактное давление при $AW = 15$ ав (13)	(16) г	—	7—14	4—7	7—9	—	—	—	—	—	—	—
Контактное давление при $AW = 25$ ав (13)	(16) г	—	11—16	11—14	11—15	—	—	—	—	—	—	15—21
Контактное давление при $AW = 90$ ав (13)	(16) г	—	—	—	—	—	—	—	—	—	—	40
Приведенное контактное давление (14)	(16) г	—	1,08	—	—	0,8—0,9	—	—	—	—	—	0,36
Приведенная сила притяжения (15)	(16) г	—	1,5—1,7	—	—	0,67—0,8	—	—	—	—	—	0,307
Отдача при 50 бодах и номинальном возбуждении (17)	%	—	85—90	—	—	—	—	—	—	—	—	> 80
Отдача при 100 бодах и номинальном возбуждении (17)	%	—	80	—	—	—	—	—	—	—	—	> 60
Искажение импульсов при номинальных ампер-витках и 50 бодах (18)	%	<5	<3	<5	—	—	—	<5	—	—	—	<1
Время срабатывания при 24 в и 50 бодах (19)	(20) мсек	—	2,5—4,5	7—13	3—5	—	—	4,5	5,5—5,0	—	—	3—4
Время перелета при 24 в и 50 бодах (21)	(20) %		< 1,7	—	—	—	—	—	—	—	—	< 10
	мсек	< 2	< 3,4	—	—	—	—	4,5—3,5	—	—	—	< 2
Время вибрации при 24 в и 50 бодах (22)	%	—	—	15—40	—	—	—	—	—	—	—	9
	мсек	—	—	3—8	—	—	—	—	—	—	—	1,8
(23) Наибольшая частота работы	(24) гц	200	200	200	100	100	100	100	100	200	200	100
Число витков основных обмоток (25)		4 × 1250	4 × 1250	17 500	23 000	2 × 23 000	28 000	4 × 1250	4 × 1250	2 × 10 000	2 × 10 000	2 × 4600
Сопротивление (26)	(27) ом	4 × 140	4 × 140	3000	6300	2 × 6500	4000	4 × 120	4 × 120	2 × 2500	2 × 2500	2 × 215
Индуктивность при 50 гц (28)	(29) гн	4 × 0,32	4 × 0,32	—	—	—	—	—	—	—	—	2 × 1,2
(28) » 25 гц (30)	(29) гн	4 × 0,35	4 × 0,35	—	—	—	—	—	—	—	—	2 × 1,5
Допустимая нагрузка обмотки	(31) вт	1	1	1	1	1	1	1	1	1	1	2
Наибольшее напряжение на обмотке и контактах (32)	(33) в	160	100	100	100	100	100	100	100	100	100	120
Номинальная величина тока в цепи контактов (34)	а	0,05	0,2	0,2	0,2	0,2	0,2	0,05	0,2	0,25—0,5	0,25—0,5	0,06
Номинальное напряжение на контактах (35)	(33)	120	24	24	24	27	27	120	27	30	30	120
Срок службы реле при номинальной нагрузке (36)	(37) циклов	10^7	10^7	10^7	10^7	$4 \cdot 10^6$	$4 \cdot 10^6$	10^7	10^7	$5 \cdot 10^5 - 10^3$	$5 \cdot 10^5 - 10^3$	10^7
Габаритные размеры реле: длина, ширина и высота (38)	мм мм	83 (98,5) 28,1 × 41	83 (96,5) 27,5 × 41	83 (96,5) 27,5 × 41	83 (96,5) 27,5 × 41	82,5 (95,5) 44 × 44	82,5 (95,5) 44 × 44	64,1 (77,1) 21 × 43,5	64,1 (77,1) 21 × 43,5	23,3 (33) 33,5 × 40	23,3 (33) 33,5 × 40	117 30 × 62
Вес реле без чехла (39)	(42) г	140	140	140	140	145	145	100	100	65	65	190
» » с чехлом (40)	(42) г	170	170	160	160	200	200	125	125	80	80	230
Вес якоря реле (41)	(42) г	4,7	4,7	4,7	4,7	1,5	1,5	4,5	4,5	0,7	0,7	2,7

Key: (1). Characteristics. (2). Unit of measurement. (3). Type of relay. (4). The sensitivity of relay (is static). (5). ampere-turns. (6). The same. (7). mW. (8). Ampere-turns of release/tempering. (9). ampere-turns. (10). Nominal excitation. (11). Gap between contacts. (12). The contact pressure with AW = 0. (13). Contact pressure when ampere-turns. (14). Given contact pressure. (15). Given attracting force. (16). g. (17). Emission during bauds and nominal excitation. (18). Distortion of momentum/impulse/pulses with nominal ampere-turns even 50 bauds. (19). Triggering time with 24 in even 50 bauds. (20). ms. (21). Time of flight/passage with 24 in even 50 bauds. (22). Chatter time with 24 in even 50 bauds. (23). Greatest frequency of work. (24). Hz. (25). Turn number of inducing windings. (26). Resistor/resistance. (27). ohm. (28). Inductance with ... Hz. (29). H. (30). Permissible load of winding. (31). W. (32). Great voltage on winding and contacts. (33). V. (34). Nominal value of circuital current of contacts. (35). Nominal voltage on contacts. (36). Service life of relay with nominal load. (37). cycles. (38). Overall dimensions of the relay: length, width and height/altitude. (39). Weight of relay without jacket. (40). with jacket. (41). Weight of the armature of relay. (42). g.

from 0.9 to 8.1 mW (6-18 ampere-turns).

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The contact system of relay consists of two motionless struts with the adjustable micrometric clamping screws and the slide contacts, riveted to two steel plates, strengthened to armature. On the caps of the adjustable clamping screws, are plotted/applied the divisions, the value of each division 0.01 mm. After the installation of the gap between contacts the adjusting screws fastened by set screws.

Contacts have flat/plane contact surface. The material of contacts is platinum. Distance between the contacts 0.10 mm. Air gap between magnet and armature 0.10-0.15 mm. Gap between pole piece and armature 0.2 mm.

A relay of the type TRM has normally neutral adjustment. The sensitivity of relay depending on adjustment can vary from 18 to 28 ampere-turns.

Contact pressure in the absence of coil current with respect is within the limits from 4 to 8 g.

The operating current of relay 15-20 mA, triggering time from 3 to 4 ms.

For the inclusion of relay into circuit, is applied special coupling block to 8 sockets. The fundamental parameters of relay of the type TRM are given in Table 13-1.

13-10. Polarized line relay of the type TRL.

A polar relay of the type TRL (Fig. 13-12) possesses very high sensitivity and high output factor. It is utilized as receiving telegraph relay in work on air and cable lines.

Relays of the type TRL are intended for operation during changes in the ambient temperature from 0 to +50°C and relative humidity to 95o/o at temperature of 20 ± 10°C. Relays maintain/withstand during 30 min vibration with frequency 10-70 Hz during accelerations respectively (5-3) g and agitation with impact acceleration to 75 g.

The magnetic circuit of the polarized line relay of the type TRL is constructed according to bridge circuit (Fig. 13-3f)in which the paths of constant and governing magnetic fluxes are divided. The permanent magnet of horseshoe form made of steel of Alni is fastened by clamp on the basis of relay. The cross section of magnet 18.5 x 6.5 mm, length 45 mm.

The core of relay is comprised of two plates of Permalloy by section 3 x 6 mm by length 69 mm on which is placed the coil. *Length of the winding space of coil* 51 mm, height/altitude its 10 mm. Inner diameter of the winding 10.9 mm. Equivalent resistance of one turn of winding 5.25 • 10^{-6} ohm (with $k_з$ = 0.39). Value $C_m = 2{,}04 \cdot 10^{-6}$ ohm.

The pole piece of relay has the increased section 8 x 13 mm. Length of magnetic circuit 2 x 49 mm.

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Core by two screw/propellers is pressed against two pole pieces of L-shaped form, assembled from sheet Permalloy.

From below against the special steel screw/propellers, which fasten the pole pieces to the foundation of relay, is pressed one of magnet poles.

Armature is riveted of two plates they will stop brand EA and was suspend/hung from steel spring by thickness 0.21 mm to brass strut. Section of armature (2 x 0.4) x 13 mm, effective length its 13 mm. To armature are screwed on two springs from the phosphor bronze by thickness 0.2 mm and by width 4 mm, carrying of their end/leads contacts from platinum.

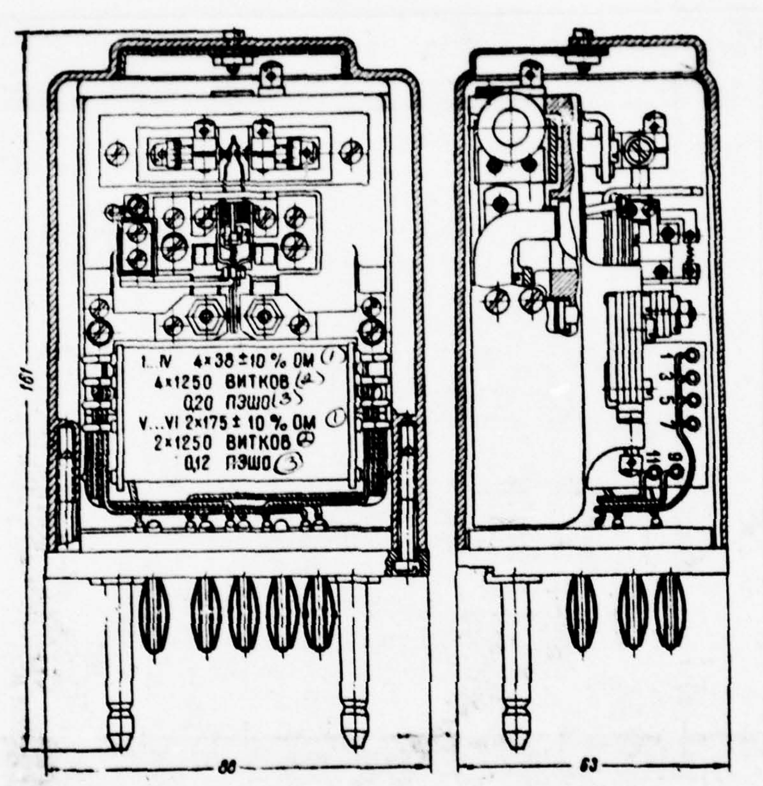

Fig. 13-12. Polarized line relay of type TRL.

Key: (1). Ohm. (2). Turns. (3). PEShO.

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For absorbing the kinetic kinetic energy of armature by friction the end/leads of the springs are bent and press to each other with force of approximately 25 g.

Fixed contacts with the adjustable screw/propellers are fastened on the special carriage which can be moved relative to housing with the aid of special micrometer gauge, equipped with drum with the divisions through 0.01 mm and placed on the front of the relay.

In the forward section of the jacket, there is a window for adjustment with the aid of the drum of the neutrality of relay in the assembled form. Is normal for protection from dust this window closed by rotary disk valve. Relay is mounted on the basis from silumin, it has special plug with two guide and as fifteen leading-out pins and it is shielded from dust by jacket from silumin.

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Chapter Fourteen.

CHARACTERISTICS OF POLAR RELAYS.

14-1. Characteristics of relay in the absence of coil current.

For simplification in the conclusion/derivations, let us assume that the induction in air gaps is distributed evenly and that the reluctance of cores and armature, and also the effect of leakage fluxes can be disregarded.

The magnetic flux of the permanent magnet, passing through the left air gap (Fig. 13-1), is equal to:

$$\Phi_1 = \frac{U_M \mu_0 S}{\sigma_1},$$

a through the right air gap

$$\Phi_2 = \frac{U_M \mu_0 S}{\sigma_2},$$

where $U_м$ is magnetic intensity, created by the permanent magnet, in ampere-turns;

σ_1 and σ_2 - the length of left and right working air gaps in m;

S - the sectional area of these gaps in m² and $\mu_0 = 4\pi \times 10^{-7}$ H/m - magnetic constant.

The general value of the polarizing magnetic flux of the permanent magnet in working air gap in the case of the absence of scattering, obviously, will be equal to:

$$\Phi_0 = \Phi_1 + \Phi_2,$$

a the relation of flows Φ_1 and Φ_2:

$$\frac{\Phi_1}{\Phi_2} = \frac{U_м \mu_0 S \sigma_2}{\sigma_1 U_м \mu_0 S} = \frac{\sigma_2}{\sigma_1}.$$

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From these equations we find:

$$\Phi_1 = \Phi_0 \frac{\sigma_2}{\sigma_1 + \sigma_2}; \qquad (14\text{-}1)$$

$$\Phi_2 = \Phi_0 \frac{\sigma_1}{\sigma_1 + \sigma_2}. \qquad (14\text{-}2)$$

The course of the armature of polar relays is usually small in comparison with the length of working air gaps; therefore the sum of flows of right and left air gaps can be considered not dependeing on the position of armature.

To the armature of polar relay in the case of the absence of coil current, operate simultaneously two forces F_1 and F_2, created by the polarizing fluxes Φ_1 and Φ_2 and directed to different sides.

Resulting force, which operates on armature, is equal to:

$$F_0 = F_1 - F_2 = \frac{1}{2\mu_0 S}(\Phi_1^2 - \Phi_2^2). \qquad (14\text{-}3)$$

Substituting for Φ_1 and Φ_2 their value, we find expression for he force, which operates on armature, in the absence of coil current of the relay:

$$F_0 = \frac{\Phi_0^2(\sigma_2 - \sigma_1)}{2\mu_0 S(\sigma_1 + \sigma_2)} = \frac{\Phi_0^2\delta}{2\mu_0 S\sigma} \quad [\text{ n }]. \qquad (14\text{-}4)$$

If we express flow in the Maxwell, orce in kilograms and size/dimensions in cm, then

$$F_0 = \frac{4{,}06 \cdot 10^{-8}\Phi_0^2\delta}{S\sigma} \quad [\text{ kgf }], \qquad (14\text{-}4a)$$

where $\sigma = \sigma_1 + \sigma_2$.

Turning moment, created by net force,

$$M_0' = F_0 l_a = \frac{\Phi_0^2 \delta l_a}{2\mu_0 S\sigma}. \qquad (14\text{-}5)$$

where $l_я$ is length of armature from rotational axis to the middle of pole. Pressure in the contacts of relay in the absence of coil current will be:

$$F'_{ко} = \frac{M_0}{l_к} = \frac{\Phi_0^2 l_я \delta}{2\mu_0 S \sigma l_к} [n] = \frac{4{,}06 \cdot 10^{-6} \Phi_0^2 l_я \delta}{\sigma S l_к} [g] \qquad (14\text{-}6)$$

where $l_к$ is a distance from the rotational axis of armature to the point of contact of contacts and $\delta = \sigma_2 - \sigma_1$ is a value of the course of armature.

When $\sigma_1 < \sigma_2$ the armature is attract/tightened to left pole, while when $\sigma_2 < \sigma_1$ - to right pole. If $\sigma_1 = \sigma_2$, then attracting force is equal to zero, but this position is very unstable, since least asymmetry or negligible external effort/force they derive/conclude armature from average position and it is moved to the side of the nearest pole to the backstop of the contact stud into fixed contact.

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From formula (14-6) it follows that the value of contact pressure in the absence of coil current of relay is proportional to the value of the course of armature (i.e. difference in $\sigma_2 - \sigma_1$), to the value of the polarizing

flux of the permanent magnet Φ_0 and inversely proportional to the distance between poles σ.

14-2. Characteristics of relay in the presence of coil current.

The operating current, which passes on windings I and II, creates the governing magnetic flux Φ_y, which is closed through gaps σ_1 and σ_2 whose value

$$\Phi_y = I(w_1 + w_2)\mu_0 \frac{S}{k_s(\sigma_1 + \sigma_2)} = Iw\frac{\mu_0 S}{k_s \sigma}, \qquad (14\text{-}7).$$

where $w_1 + w_2 = w$ and k_s - the coefficient of scattering the magnetic circuit of governing flow.

Furthermore, operating current creates also the flows, which are closed through armature and magnet, but the values of these flows are small and them can be disregarded.

Resulting values of the flows, created by the permanent magnet and operating current in gaps σ_1 and σ_2, are respectively equal to:

$$\Phi_1' = \Phi_1 \mp \Phi_y = \Phi_0 \frac{\sigma_2}{\sigma} \mp \frac{Iw\mu_0 S}{k_\sigma \sigma}$$

and

$$\Phi_2' = \Phi_2 \pm \Phi_y = \Phi_0 \frac{\sigma_1}{\sigma} \pm \frac{Iw\mu_0 S}{k_\sigma \sigma},$$

where plus signs and minus they correspond to opposite directions of flow in the winding of relay.

Net force of attraction, which operates on the armature of relay in the presence of coil current, is equal to:

$$F = \frac{\Phi_1'^2 - \Phi_2'^2}{2\mu_0 S} = \frac{\Phi_1^2 - \Phi_2^2}{2\mu_0 S} \mp \frac{\Phi_0 \Phi_y}{\mu_0 S} = \\ = \frac{\Phi_0^2 (\sigma_2^2 - \sigma_1^2)}{2\mu_0 S \sigma^2} \mp \frac{\Phi_0 Iw}{k_\sigma \sigma} = \frac{\Phi_0^2 \delta}{2\mu_0 S \sigma} \mp \frac{\Phi_0 AW}{k_\sigma \sigma}, \quad (14\text{-}8)$$

and turning moment of relay in the presence of coil current

$$M_1' = \frac{\Phi_0^2 \delta l_{я}}{2\mu_0 S \sigma} \mp \frac{\Phi_0 AW}{k_\sigma \sigma} l_{я} = M_0' \mp M_y, \qquad (14\text{-}9)$$

where M_y is turning moment, created controlling flow:

$$M_y = \frac{\Phi_0 AW}{k_\sigma \sigma} l_{я}. \qquad (14\text{-}10)$$

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Consequently, resulting moment, which operates on the armature of relay at the moment of its contact/start (when $\sigma_1 < \sigma_2$), is equal to a difference in the worker

torque/moment M_y, created by governing flow and approaching to move armature the right contact, and torque/moment M_0, created by the polarizing direct flow, which attempts to retain/hold down armature of left contact.

After the function of relay (transfer of armature) resulting moment is equal to the sum of torque/moments M_y and M_0.

Pressure in the contact of relay when there is present in the winding a current, which exceeds spill current, will be equal to:

$$F_к' = \frac{\Phi_0^2 l_я \delta}{2\mu_0 S\sigma l_к} + \frac{\Phi_0 l_я AW}{k_\sigma \sigma l_к} = F_{к0}' + F_{ку} \quad [n], \qquad (14\text{-}11)$$

where $F_{ку}$ is the boost pressure in contact, created by the control current, which takes place on the winding of relay.

If we express flow in μs, force in g and size/dimensions in cm, then

$$F_к' = \frac{4{,}06\cdot 10^{-6}\Phi_0^2 l_я \sigma}{\sigma S l_к} + \frac{1{,}02\cdot 10^{-4}\Phi_0 l_я AW}{k_\sigma \sigma l_к} \quad [g]. \qquad (14\text{-}11a)$$

The moment of operation (contact/start) of relay is

The moment of operation (contact/start) of relay is determined that by the equality of controlling and holding torque/moments $M_y = M_0$; in this case

$$\frac{\Phi_0^2 \delta l_я}{2\mu_0 S\sigma} = \frac{\Phi_0 l_я AW_c}{k_e \sigma}.$$

We hence find expression for the ampere-turns of the function of the relay, which does not have the spring suspension of the armature:

$$AW_c = \frac{\Phi_0 k_e \delta}{2\mu_0 S}. \qquad (14\text{-}12)$$

From the obtained expression it follows that for a decrease in the ampere-turns of function it is necessary to decrease the polarizing flux of the permanent magnet and the course of armature. However, it is not difficult to ascertain that in this case the pressure in contact in the absence of coil current decreases.

If we substitute flow in the Maxwell, size/dimensions in cm and $\mu_0 = 4\pi \cdot 10^{-7}$, then we will obtain for the ampere-turns of the function of the relay, which does not have the spring suspension of armature,

$$AW_c = \frac{0.398\Phi_0 k_e}{S}\delta. \qquad (14\text{-}12a)$$

14-3. Characteristics of relay with the suspension spring of armature.

Of the newest types of polar relays (RP, RPS, TRL) the armature is suspended on flat/plane steel or bronze spring.

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The reactionary torque, created by the suspension spring of armature,

$$M_{\text{п}} = a_1\varphi \approx a_1 \frac{\delta}{l_{\text{я}}}, \qquad (14\text{-}13)$$

where ϕ is an angle of deflection of armature from neutral and a_1 - spring constant.

Resulting moment which operates on the armature of relay, spring-mounted, in the absence of coil current is equal to:

$$M_0 = M_0' - M_{\text{п}} = \frac{\Phi_0^2 l_{\text{я}} \delta}{2\mu_0 S\sigma} - a_1 \frac{\delta}{l_{\text{я}}} = \left(\frac{\Phi_0^2 l_{\text{я}}}{2\mu_0 S\sigma} - \frac{a_1}{l_{\text{я}}}\right)\delta. \qquad (14\text{-}14)$$

If the torque/moment, created by the constant polarizing flux of magnet, the more reactionary torque of spring $M_0' > M_{\text{п}}$, then the contact of armature is always pressed to one of the fixed contacts (to any). This operating mode is called two-position.

Pressure in contact in the absence of coil current will be:

$$F_{\text{к}0}=\frac{M_0}{l_{\text{к}}}=\left(\frac{\Phi_0^2 l_{\text{я}}}{2\mu_0 S\sigma l_{\text{к}}}-\frac{a_1}{l_{\text{я}} l_{\text{к}}}\right)\delta \quad [n]$$

or

$$F_{\text{к}0}=\left(\frac{4{,}06\cdot 10^{-5}\Phi_0^2 l_{\text{я}}}{\sigma S l_{\text{к}}}-\frac{a_1}{l_{\text{я}} l_{\text{к}}}\right)\delta \quad [g] \qquad (14\text{-}15)$$

For magnetic systems with four working gaps (Fig. 13-3d), during the two-position operating mode pressure in contact in the absence of coil current

$$F_{\text{к}0}=\left(\frac{\Phi_0^2 l_{\text{я}}}{\mu_0 S\sigma l_{\text{к}}}-\frac{a_1}{l_{\text{я}} l_{\text{к}}}\right)\delta \ [n] \quad \text{or} \quad F_{\text{к}0}=\left(\frac{8{,}12\cdot 10^{-5}\Phi_0^2 l_{\text{я}}}{\sigma S l_{\text{к}}}-\frac{a_1}{l_{\text{я}} l_{\text{к}}}\right)\delta \ [g] \qquad (14\text{-}15a)$$

i.e. is almost two times more than for magnetic systems with two working gaps.

On the contrary, if $M_n > M_0'$, then occurs the three-position operating mode, during which the armature of relay remains in average/mean (neutral) position in the absence of coil current. In this case the slide contact clear not one of the fixed contacts, and for the contact of contacts it is necessary to apply the supplementary torque/moment

$$M_{\text{д}} = \left(\frac{a_1}{l_{\text{я}}} - \frac{\Phi_0^2 l_{\text{я}}}{2\mu_0 S\sigma}\right)\delta. \qquad (14\text{-}16)$$

When, in the winding, current relay are present,, which exceeds the spill current, resulting moment, which operates on the armature, spring-mounted, before and after the function of relay will be:

$$M_i = M_0 \mp M_y = \left(\frac{\Phi_0^2 l_{\text{я}}}{2\mu_0 S\sigma} - \frac{a_1}{l_{\text{я}}}\right)\delta \mp \frac{\Phi_0 AW}{k_e\sigma} l_{\text{я}}. \qquad (14\text{-}17)$$

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Pressure in the contact of relay when there is present in the winding a current, which exceeds spill current, will be equal to:

$$F_к = \left(\frac{\Phi_0^2 l_я}{2\mu_0 S\sigma l_к} - \frac{a_1}{l_я l_к}\right)\delta + \frac{\Phi_0 l_я AW}{k_e \sigma l_к} \quad [n]$$

$$F_к = \left(\frac{4{,}06 \cdot 10^{-8}\Phi_0^2 l_я}{\sigma S l_к} - \frac{a_1}{l_я l_к}\right)\delta + \frac{1{,}02\Phi_0 l_я AW}{10^4 k_e \sigma l_к} = F_{к0} + F_{ку} \quad [g] \qquad (14\text{-}18)$$

Relay will actuate/operate when the torque/moment, created by governing flow, exceeds the value of turning moment M_0, created by the polarizing flux,

$$M_у - M_0 \geqslant 0 \quad \text{or} \quad M_0 = M_{ус}, \qquad (14\text{-}19)$$

where $M_{ус}$ - turning moment, created by governing flow when $AW = AW_c$.

Consequently,

$$\left(\frac{\Phi_0^2 l_я}{2\mu_0 S\sigma} - \frac{a_1}{l_я}\right)\delta = \frac{\Phi_0 AW_c}{k_e \sigma} l_я,$$

whence we find expression for the ampere-turns of the function of two-position relay with the spring suspension of the armature:

$$AW_c = \left(\frac{\Phi_0}{2\mu_0 S} - \frac{a_1 \sigma}{\Phi_0 l_я^2}\right) k_e \delta. \qquad (14\text{-}20)$$

For the function of three-position relay, it is necessary that turning moment, created by governing flow, will exceed torque/moment $M_{д}$:

$$M_{у}-M_{д}\geqslant 0 \quad \text{or} \quad M_{д}=M_{у\,ср}$$

Consequently,

$$\left(\frac{a_1}{l_{я}}-\frac{\Phi_0^2 l_{я}}{2\mu_0 S\sigma}\right)\delta=\frac{\Phi_0 AW_{с} l_{я}}{k_{о}\sigma}.$$

Hence the ampere-turns of the function of three-position relay

$$AW_{с}'=\left(\frac{a_1\sigma}{\Phi_0 l_{я}}-\frac{\Phi_0}{2\mu_0 S}\right)k_{о}\delta. \qquad (14\text{-}21)$$

If we express flow in the Maxwell and size/dimensions in cm, then for the two-position relay

$$AW_{с}=\left(\frac{0{,}398\Phi_0}{S}-\frac{a_1\sigma\cdot 10^4}{1{,}02\Phi_0 l_{я}^2}\right)k_{о}\delta \qquad (14\text{-}20a)$$

and for three-position

$$AW_{с}'=\left(\frac{a_1\sigma\cdot 10^4}{1{,}02\Phi_0 l_{я}^2}-\frac{0{,}398\Phi_0}{S}\right)k_{о}\delta. \qquad (14\text{-}21a)$$

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For magnetic systems with four working air gaps during the two-position operating mode the ampere-turns of the

function

$$AW_c = \left(\frac{0{,}398\Phi_0}{S} - \frac{a_1\sigma \cdot 10^4}{2{,}04\Phi_0 l_{\text{я}}^2}\right)k_0\delta \qquad (14\text{-}20b)$$

and during the three-position conditions/mode of the work

$$AW_c' = \left(\frac{a_1\sigma \cdot 10^4}{2{,}04\Phi_0 l_{\text{я}}^2} - \frac{0{,}398\Phi_0}{S}\right)k_0\delta. \qquad (14\text{-}21b)$$

From formulas (14-20) and (14-21) it follows that the ampere-turns of the function of polar relays the lesser, the lesser the course of armature, the coefficient of scattering and the reluctance of the circuit of governing flow. Disregarding the reluctance of the material of magnetic circuit, it is possible to consider the reluctance of the circuit of governing flow equal to the reluctance of working air gap.

On the other hand, the lesser the value of the polarizing direct flow, is more the rigidity of the elastic suspension of armature and is more the length of working air gaps, the lesser the ampere turns of the function of two-position relay and greater - three-position.

Dependence of contact pressure on the ampere-turns of function.

Dependence of contact pressure on the ampere-turns of function.

At the moment of the function of relay, according to equation (14-19),

$$M_{\circ}=F_{\kappa\circ}l_{\kappa}=M_{yc},$$

whence pressure in the contact

$$F_{\kappa\circ}=\frac{M_{yc}}{l_{\kappa}}=\frac{F_{yc}l_{\kappa}}{l_{\kappa}}. \qquad (14\text{-}22)$$

According to expressions (14-7) and (14-8),

$$F_{yc}=\frac{\Phi_{0}\Phi_{yc}}{2\mu_{0}S}=\frac{\Phi_{0}AW_{c}}{k_{\sigma}\sigma} \quad [n].$$

If we express flow in the Maxwell, pressure in G and size/dimensions in cm, then

$$F_{yc}=\frac{1{,}02\Phi_{0}AW_{c}'}{10^{4}\sigma k_{\sigma}} \quad [G]$$

After substituting into equation (14-22) instead of F_{yc} its value from last/latter expression, we will obtain formula for pressure in contact in the absence of coil current of the relay:

$$F_{\kappa\circ}=\pm\frac{1{,}02\Phi_{0}l_{\pi}AW_{c}}{10^{4}k_{\sigma}\sigma l_{\kappa}}, \qquad (14\text{-}23)$$

where plus sign it corresponds to two-position and minus sign - to the three-position mode of the work of relay.

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Substituting in expression (14-18) instead of $F_{\kappa0}$ its value from equation (14-23), we obtain for the contact pressure of relay in the presence of coil current the following expression:

$$F_{\kappa}=\frac{1{,}02\Phi_{0}l_{\pi}}{10^{4}k_{0}\sigma l_{\kappa}}(AW\pm AW_{c}), \qquad (14\text{-}24)$$

where the positive sign (+) is related to two-position, and sign "minus" (-) to the three-position mode of the work of relay.

From expressions (14-23) and (14-24) follows that at constant values Φ_0 and σ and in absence of coil current pressure in the contact of two-position relay is proportional to its ampere-turns of function.

In the presence of coil current contact pressure approximately of proportionally to the sum working ampere-turns and ampere-turns of function of two-position and to a difference in these ampere-turns of three-position relay.

At equal values Φ_0, AW and AW_0 the contact pressure of three-position relay is less than two-position one, at the doubled value of pressure F_{k0} in the absence of coil current.

The contact pressure of relay at assigned values of ampere turns does not depend on the course of armature and rigidity of suspension, it of the directly proportionally to the value polarizing flux and vice versa is proportional to the length of air gaps.

Criteria for evaluating the polar relays.

As a result of work on the investigation of polar relays T.K. Shtremberg it will introduce for the evaluation of the quality of polar relays the concept of the given attracting force and the given contact pressure.

According to expression (14-23) the pressure in the contact of polar relay in the absence of coil current is

proportional to the ampere-turns of the function of this relay. It is consequent, the ratio of contact pressure to the ampere-turns of the function of relay (given contact pressure) characterizes by itself the quality (emission) of relay and can be used as criterion for the evaluation of the quality of the polar relays:

$$F_{\text{к01}} = \frac{F_{\text{к0}}}{AW_c} = \frac{1{,}02\Phi_0 l_{\text{п}}}{10^4 k_s \sigma l_{\text{к}}}. \qquad (14\text{-}25)$$

From expression (14-24) we find:

$$F_{\text{к0}} = \frac{F_{\text{к}}}{AW \pm AW_c}.$$

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It is necessary to note that the last/latter formula is valid only at comparatively low values of the working ampere-turns when does not manifest itself the effect of the saturation of material of the magnetic circuit of relay.

In the presence of coil current, the contact pressure, led to $AW_0 = 1$, will be equal to:

$$F_{\text{к1}} = \frac{1{,}02\Phi_0 l_{\text{п}}}{10^4 k_s \sigma l_{\text{к}}}(AW \pm 1) = F_{\text{к0}}(AW \pm 1). \qquad (14\text{-}25\text{a})$$

For evaluating the construction of the magnetic systems of polar relays, it is necessary to use the ratio of the

attracting force of the armature of relay in the absence of coil current to the ampere-turns of the function of relay. This value is called the given attracting force of the armature of the relay:

$$F_{01}=\frac{F_{\kappa 01}l_{\kappa}}{l_{\kappa}}=\frac{F_{\kappa 0}l_{\kappa}}{AW_c l_{\kappa}}=\frac{1{,}02\Phi_0}{10^4 k_\sigma \sigma} \qquad (14\text{-}26)$$

or

$$F_{01}=\frac{F_{\kappa}l_{\kappa}}{(AW\pm AW_c)\,l_{\kappa}}.$$

In the presence of coil current, the attracting force of the armature of relay, led to $AW_c=1$, is equal to:

$$F_1=\frac{1{,}02\Phi_0}{10^4 k_\sigma \sigma}(AW\pm 1)=F_{01}(AW\pm 1). \qquad (14\text{-}26a)$$

From expressions (14-27) and (14-28) follows that for an increase in the given attracting force it is necessary to increase the polarizing magnetic flux and to decrease the coefficient of scattering and the value of working air gaps.

However, an increase in the polarizing flux will lead to an increase in the ampere-turns of the function of two-position and a decrease in the ampere-turns of the function of three-position relay. For the preservation/retention/maintaining of the assigned magnitude of the ampere-turns of function, it is necessary simultaneously

with an increase of the flow to increase the rigidity of the suspension of armature, also, within the limits of the possible to decrease the course of armature of two-position and to increase it in three-position relay.

It is necessary to keep in mind that a decrease in the working air gaps and course of armature leads to a decrease in the stability of the parameters of relay. Values of the given contact pressure and given attracting force for the different types of polar relays are given in table 13-1.

Dependence of the ampere-turns of function and contact pressure on the value of polarizing flux and rigidity of the elastic suspension of armature.

From expressions (14-20) and (14-21) follows that with a decrease in the polarizing constant magnetic **flux** Φ_0 the ampere-turns of the function of two-position relay decrease, and three-position - they increase.

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The minimum value of the ampere-turns of function corresponds to the condition of the transition of relay from the two-position operating mode to three-position. With values of the constant polarizing magnetic flux

$$\Phi = \Phi_0 = \frac{1}{l_n}\sqrt{2a_1\mu_0 S\sigma}, \qquad (14\text{-}27)$$

of relay it passes of one operating mode in another and the ampere-turns of function are equal to zero.

However, according to expression (14-23) contact pressure in this case is equal to zero; therefore to work under these conditions is impossible.

The dependence of the ampere-turns of function on the value of the polarizing flux is graphically expressed by the difference between the straight line, the passing through the origin of coordinates, and equilateral hyperbola whose curvature is determined by the rigidity of the suspension of armature.

The dependence of contact pressure on flow value [formula (14-18)] is graphically expressed by the positive branch of the parabola of the square of form $c\Phi^2 + c_1\Phi - c_2$,

the ordinate of apex/vertex of which C_2 is proportional to the constant elasticity of the suspension of armature. Figures 14-1 and 14-2 gives the curves of the dependences of the ampere turns of function and contact pressure of relay of the type RP on the value of polarizing flux and thickness of the suspension spring of armature at 2σ = 2 x 0.45 mm, 2Δ = 2 x 0.04 mm and 2Δ = 2 x 0.1 mm, obtained experimentally T. K. Shtremberg.

A relay of type RP-4 has suspension spring as thickness 0.23 mm and 2Δ = 0.08 mm, while relay of type RP-5 - a suspension spring by thickness 0.28 mm and 2Δ = 2 x 0.10 mm.

From the curves of Fig. 14-1b and 14-2b, it follows that at large values of the polarizing constant magnetic flux both relays - RP-4 and RP-5 - work in two-position conditions/mode; with a decrease in the direct flow, the ampere-turns of the function of both relays decrease and reach in turn zero when Φ_0, equal to 1.5 • 10^{-5} and 1.85 • 10^{-5} Wb. During a further decrease in the direct flow, both relays alternately pass to the three-position mode of operation and the ampere-turns of the function of these relays respectively increase.

A relay of type RP-4, which has the suspension spring of armature as thickness 0.23 mm with the constant value flow in $1.7 \cdot 10^{-5}$ Wb, works in two-position conditions/mode and has sensitivity of approximately 0.8 ampere-turns, while a relay of type RP-5 with suspension spring by thickness 0.28 mm with the same constant value flow works in three-position conditions/mode and has sensitivity 1.6 ampere-turns.

The thicker the suspension spring of armature, the greater the value Φ_0, at which the relay transfers into two-position conditions/mode.

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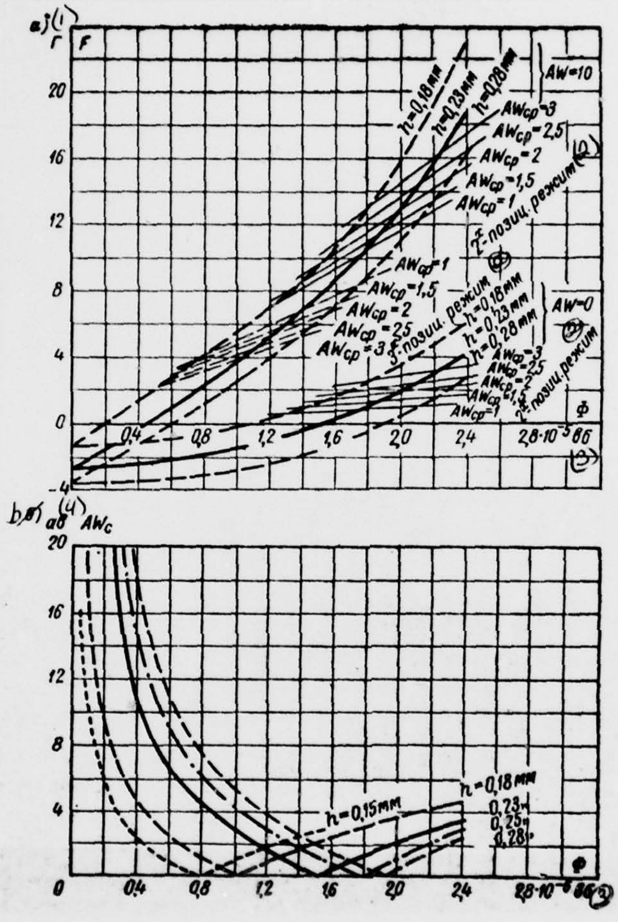

Fig. 14-1. Curved of dependences of ampere-turns of function and contact pressure of relay of type RP on value of polarizing flux and thickness of suspension spring of armature (2σ = 2 x 0.45 mm; 2Δ = 0.8 mm). Solid lines is two-position conditions/mode; broken - three-position conditions/mode.

Key: (1) g; (2) position conditions/mode; (3) Wb; (4) AV.

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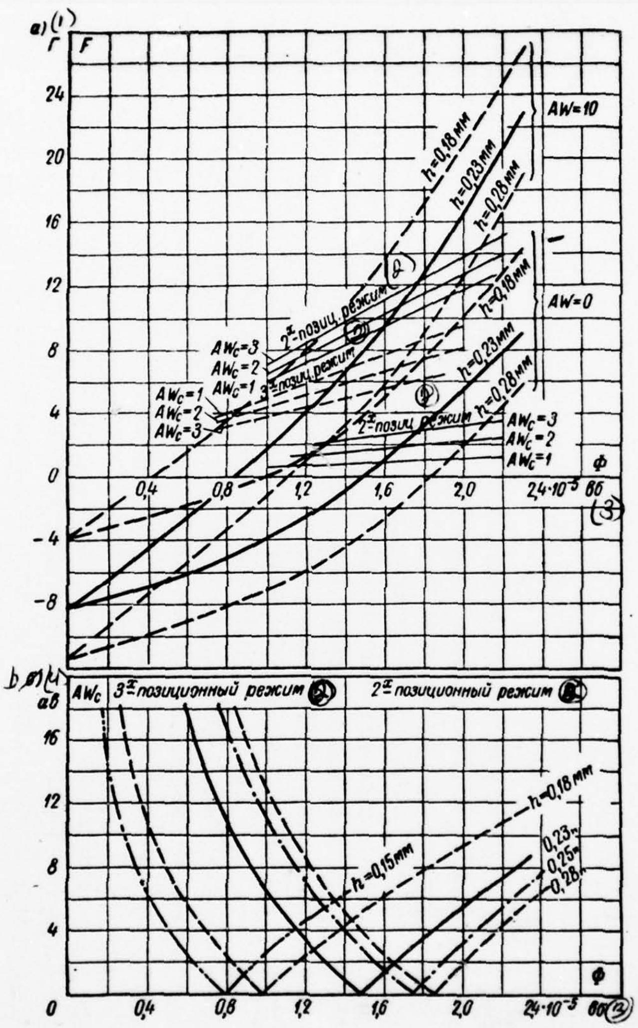

Fig. 14-2. **Curved of dependences** of ampere-turns of function and contact pressure of relay of type RP on value of polarizing flux and thickness of suspension spring of armature (2σ = 2 x 0.45 mm; 2Δ = 2 x 0.1 mm). Solid

lines is two-position conditions/mode; broken - three-position conditions/mode.

Key: (1). g. (2). Position conditions/mode. (3). Wb. (4). AV.

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The curves of Fig. 14-1a intersect by the fine/thin lines, which are the locus of the contact pressures, which correspond equal to values of the ampere-turns of function. These lines are straight lines, that pass approximately through beginning coordinates.

Consequently, the contact pressure of the relays, which have the different rigidity of the suspension of armature, but controlled with the aid of the polarizing flux to identical sensitivity, grow/rises of proportionally to the value this flow.

Table 14-1 gives corrected values of contact pressure for the relays of types RP-4 and RP-5 with the different thickness of suspension spring and the different ampere-turns

of function and working ampere turns, obtained T. K. Shtremberg from Fig. by 14-1 for relay of type RP-4 and from Fig. 14-2 for relay of type RP-5.

From table it follows that an increase in the thickness of suspension spring s from 8 to 0.28 mm makes it possible to increase contact pressure cf relay of type RP-4 on 40-60o/o and of relay of type RP-5 on 70-80o/o with the same sensitivity and the corresponding increase in the polarizing flux.

Dependence of the ampere-turns of function and contact pressure on the course of armature.

From expressions (14-15), (14-18), and (14-20) follows that the ampere-turns of function and contact pressure depend linearly on the course of armature.

Table 14-1. Pressure in the contacts of polar relays with the different ampere-turns of function and the rigidity of the suspension of armature.

	(2) Тип РП-4 ($2\Delta = 0{,}08$ мм)					(2) Тип РП-5 ($2\Delta = 2 \times 0{,}1$ мм)		
AW_{cp}, ав (1)	h, мм	$\Phi \cdot 10^{-5}$, вб (3)	F_0, Г (4)	F_{10}, Г (4)	F_{15}, Г (4)	$\Phi \cdot 10^{-5}$, вб (3)	F_{10}, Г (4)	F_{15}, Г (4)
1,5	0,18	1,36	0,9	8,4	12,0	0,87	4,2	6,6
	0,23	1,85	1,25	11,4	16,0	1,35	6,1	9,3
	0,28	2,21	1,5	13,6	18,8	1,71	7,5	11,3
2,0	0,18	1,5	1,4	9,6	13,7	0,83	3,8	6,1
	0,23	1,97	1,9	12,7	17,6	1,31	5,6	8,7
	0,28	2,32	2,2	15,1	20,4	1,66	6,8	10,7
2,5	0,18	1,63	1,9	11,1	15,3	0,80	3,5	5,6
	0,23	2,09	2,4	14,3	19,3	1,27	5,1	8,2
	0,28	2,42	2,8	16,6	22,2	1,61	6,1	10,1
3,0	0,18	1,79	1,79	13,0	17,4	0,76	3,1	5,2
	0,23	2,22	2,22	16,1	21,3	1,24	4,5	7,7
	0,28	2,51	2,51	18,2	24,0	1,56	5,5	9,4

Key: (1). A V. (2). Type. (3). Wb. (4). g.

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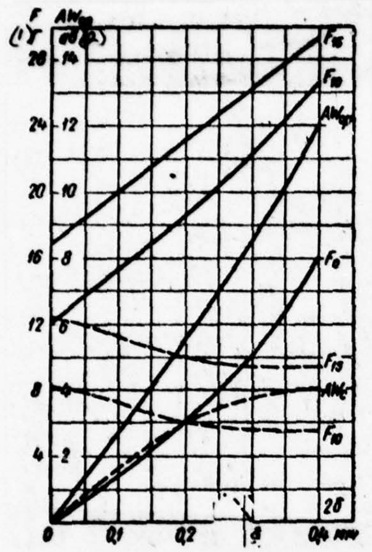

Fig. 14-3.

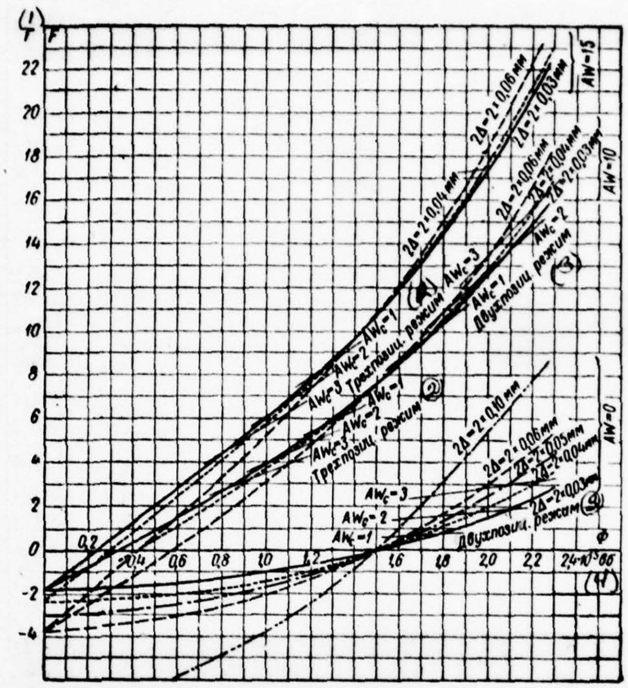

Fig. 14-4.

Fig. 14-3. Curved of dependences of ampere-turns of triggering and contact pressure of relay of type RP on distance between contacts. Solid lines - type RP-4; broken lines is type RP-5.

Key: (1). g. (2) AV.

Fig. 14-4. Curved of dependences of contact pressure of relay of type RP on value of polarizing flux at different distances between contacts. Solid lines is two-position

conditions/mode; broken - three-position conditions/mode.

Key: (1). g. (2). Three-position conditions/mode. (3). Two-position conditions/mode. (4). Wb.

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Figures 14-3 gives the curves of the dependences of the ampere-turns of function and contact pressure on the distance between contacts for the relay of types RP-4 and RP-5. The sagging/deflection of flexible contact stud of relay of the type RP is insignificant; therefore the dependence between the course of armature and the distance between contacts is equal to:

$$\delta \approx \frac{l_{\kappa}}{l_{\kappa}}\Delta. \qquad (14\text{-}28)$$

From curves, given in Fig. 14-3, it follows that the dependences of the ampere-turns of function and contact pressure of relay of the type RP on the distance between contacts of value 2Δ = 0.2 mm are straight lines. The disturbance/breakdown of the linearity of these dependences at the large values of quantity 2Δ is explained, apparently, by an increase in the polarizing flux whose value during analytical conclusion/derivations was accepted which does not depend on the position of armature.

that which not depends on the position of armature.

With an increase in the course of armature, the contact pressure of relay of type RP-4 increases, and of relay of type RP-5, it decreases.

Figures 14-4 and 14-5 gives the curves of the dependences of the ampere-turns of function and contact pressure of relay of the type RP on the value of the polarizing flux at the different values of the distance between contacts (course of armature).

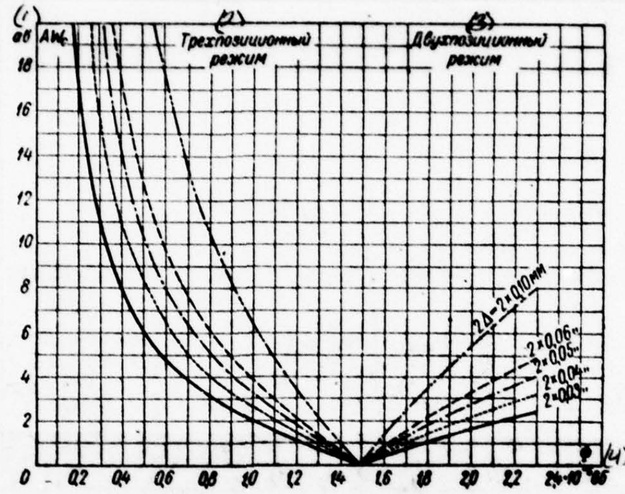

Fig. 14-5. **Curved of dependences of ampere-turns of** function of relay of type RP on value of polarizing flux at different distances between contacts. Solid lines is two-position conditions/mode; broken - three-position conditions/mode.

Key: (1). AV. (2). Three-position conditions/mode. (3). Two-position conditions/mode. (4). Wb.

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Table 14-2 gives the values of the contact pressure of the relays of types RP-4 and RP-5 with different sensitivity at the different gaps between contacts, obtained from the curves of Figs. 14-4 and 14-5.

From the data of table 14-2, it follows that a decrease in the gap between contacts from 0.12 to 0.06 mm makes it possible to increase contact pressure of relay of the type RP on 15-40o/o with the appropriate increase in the polarizing flux. Of relay of type RP-5, on the contrary, an increase in the gap between contacts with 2 x 0.06 mm to 2 x 0.1 mm raises contact pressure on 13-20o/o (with the thickness of the spring of armature 0.23 mm).

Analyzing that which was presented, it is easy to be convinced of the fact that in the final analysis for an increase in the contact pressure of polar relays it is necessary to increase the polarizing constant magnetic flux, which operates on armature. A simultaneous increase in the

thickness of the suspension spring of armature and a change in the gap between contacts (course of armature) is necessitated the preserving of the assigned ampere-turns of the function of relay.

Table 14. Pressure in the contacts of polar relays with the different ampere-turns of function and the courses of armature.

$AW_{ср}$, ав	Двухпозиционный режим (1)			Трехпозиционный режим (2)		
	2Δ, мм	F_{10}, Г	F_{15}, Г	2Δ, мм	F_{10}, Г	F_{15}, Г
1	0,06 0,12	10,2 9,0	14,2 12,5	2 × 0,06 2 × 0,10	6,2 6,8	9,0 10,2
2	0,06 0,12	14,0 10,0	19,6 14,6	2 × 0,06 2 × 0,10	5,0 5,6	7,6 9,1
2,5	0,06 0,12	16,7 11,7	22,9 16,0	2 × 0,06 2 × 0,10	4,5 5,1	6,9 8,3
3	—	—	—	2 × 0,06 2 × 0,10	4,0 4,6	6,3 7,8

Key: (1). Two-position conditions/mode. (2). Three-position conditions/mode.

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Dependence of the ampere-turns of function and contact pressure on the length of working air gaps.

Figures 14-6 gives the curves of the dependences of the ampere-turns of function on the length of working air gaps, and also contact pressure on the length of working air gaps with different values of working ampere-turns for relay of the type RP with suspension springs by thickness 0.23 mm (2Δ = 0.08 mm) and 0.28 mm (2Δ = 2 x 0.1 mm).

From these curves it follows that the ampere-turns of the function of relay with an increase in the length of air gaps first decrease, and then they begin to increase.

The minimum value of ampere-turns for triggering corresponds to the value of the polarizing flux $\Phi = \Phi_0$, with which the relay passes from two-position conditions/mode to three-position. Contact pressure decreases with an increase in the length of working air gaps.

Figures 14-7 gives average the curves of the dependences of contact pressure on the value of working ampere-turns for the relay of types TRM, RP-4, RP-5, RP-7, RPS-4, RPS-5 and TRL, obtained by T. K. Shtremberg.

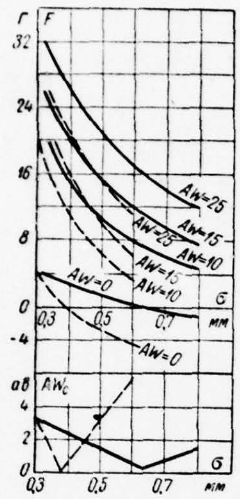

Fig -14.6.

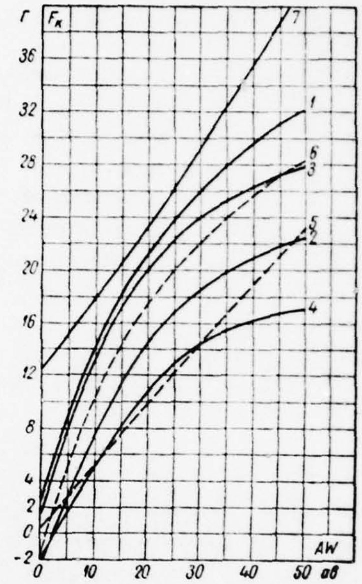

Fig. 14.7.

Fig. 14-6. Curved of dependences of ampere-turns of function and contact pressure of relay of type RP on length of working air gaps. Solid lines is thickness of spring 0.23 mm; 2Δ = 0.08 mm; broken lines is thickness of spring 0.28 mm; 2Δ = 2 x 0.1 mm.

Fig. 14.7. Curved of dependences of contact pressure of relay on value of working ampere-turns. 1 - type RP-4; 2 - type RP-5; 3 - type RP-7; 4 - type RPS-4; 5 - type RPS-5; 6 - type TRL; 7 - type TRM.

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)

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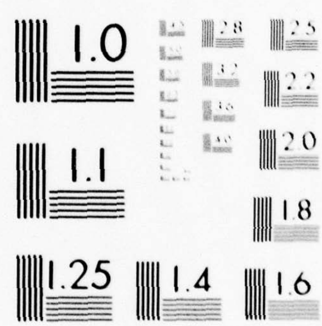

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The length of the working air gap of relay of the type RP is equal to 0.45 mm (from each side); with AW = 100 AW this length decreases approximately to 0.35 mm as a result of the sagging/deflection of the contact springs of armature. It is necessary to note that the value of the contact pressure of polar relays can oscillate over wide limits [approximately to ±(20-50)o/o from average value] due to the effect of tolerances in size of parts and fluctuations of the regulating parameters of relay.

The attracting force of the armature of these relays is equal to the contact pressure, multiplied on the relation of the arms of contact and armature whose value for relay of the type RP is equal to 1.41, for relay of the type RPS - 1.0 for relay of the type TRM - 0.845 and for relay of the type TRL - 1.69.

Empirical formulas for the calculation of the attracting force of polar relays.

Figures 14-8 gives on logarithmic scale the average full-load saturation curves of the polar relays of types RP-4, RP-5 and RP-7, constructed with the aid of the curves of Fig. 14-7.

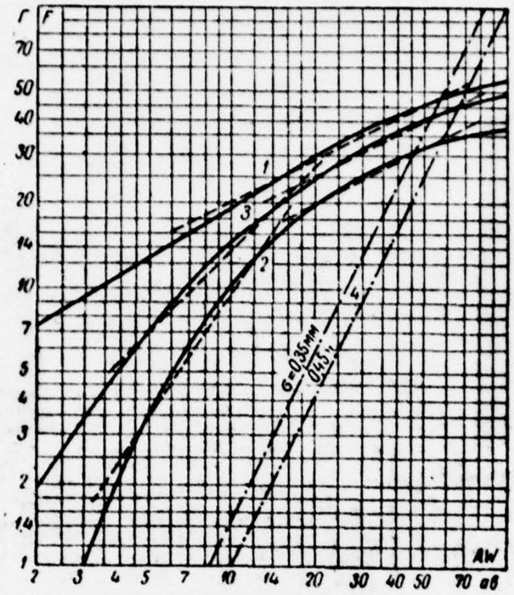

Fig. 14-8. Full-load saturation curves of polar relays. 1 - type RP-4; 2 - type RP-5; 3 - type RP-7; 4 - type RKM-1.

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For a comparison dot-dash line are constructed the full-load saturation curves of an electromagnetic neutral relay of type RKM-1 when σ = 0.35 and 0.45 mm, which has approximately the same surface of pole (weight they stopped the magnetic system of relay of type RKM-1 - 86 g and C_m = $= 3{,}24\cdot10^{-6}$ ohm; the weight of steel of the magnetic system of

relay of the type RP - 107 g and $C_m = 4{,}25 \cdot 10^{-6}$ ohm).

From these curves it follows that approximately to 50-60 AV the attracting force of the polar relays is more than neutral ones, moreover the advantage of polar relays increases with a decrease in the ampere-turns [AV] of excitation.

With 10 AV the attracting force of a polar relay of type RP-7 is 14.5 times more than relay of type RKM-1.

Within limits approximately from 4 to 20 AV the average value of the attracting force of relay of type RP-7 can be approximated by the following approximation empirical formula:

$$F \approx 0{,}28 \frac{AW}{\sigma^2} \ [g], \qquad (14\text{-}29)$$

where σ - a half of the length of working air gap in mm.

This formula is used within the limits of change σ approximately from 0.3 to 0.7 mm. With value σ = 0.45 mm, the average value of the attracting force of relay of type RP-7 will be:

$$F \approx 1{,}4AW.$$

During excitation within limits from 12 to 80 AV

$$F \approx 5{,}6\sqrt{AW}. \qquad (14\text{-}29a)$$

Average value of the attracting force of relay of type RP-4 within limits from 6 to 80 AV

$$F \approx 0{,}59\frac{\sqrt{AW}}{\sigma^3}. \qquad (14\text{-}29b)$$

With value σ = 0.45 mm the average value of the attracting force of relay of type RP-4

$$F \approx 6{,}5\sqrt{AW}.$$

Within limits from 4 to 16 AV the average value of the attracting force of relay of type RP-5

$$F \approx 0{,}028\frac{\sqrt{AW^3}}{\sigma^3}. \qquad (14\text{-}29c)$$

With value σ = 0.45 mm the average value of the attracting force of relay of type RP-5

$$F \approx 0{,}31\sqrt{AW^3},$$

a within limits from 15 to 80 AV

$$F \approx 4{,}5\sqrt{AW}. \qquad (14\text{-}29d)$$

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Dependence ampere - [redacted] turns of the function of relay on frequency.

Figures 14-9 gives tentative the curves of the dependences of the ampere-turns of the function of relay of type RP-4 on the frequency of the feeding alternating current. From these curves it follows that a relay of type RP-4 can work at the frequencies of more than 300 Hz, but at frequencies above 200 Hz the ampere-turns of the function of relay sharply grow/rise.

14-4. Time of the motion of armature.

a) armature with rigid reed.

Let us assume that the current, passing through the windings of relay, changes instantly from value $-I_0$ to $+I_0$.

Eddy-current effect and bearing friction we disregard.

The torque/moment, created by constant magnetic flux $M_{\text{м}}\alpha$, during the motion of armature changes, passing through the zero value in the mid-position of armature, i.e., when $\alpha = 0$.

Alternate angles let us consider negative, if armature is located to the left from center line, and positive, if it is located to the right. The armature of relay will begin to move at that torque/moment, when the torque/moment, created by current, is equalized with the torque/moment, created by the direct flow [redacted] [13-1].

The differential equation of motion of armature with rigid reed will be:

$$J\frac{d^2\alpha}{dt^2} - M_{\text{м}}\alpha = M_i I_0,$$

where J - the moment of the inertia of armature relative to rotational axis,

$M_{\text{м}}\alpha$ - the torque/moment, created by the direct flow,

$M_i I_0$ - the torque/moment, created by control current, and

α - an angle of deflection of armature.

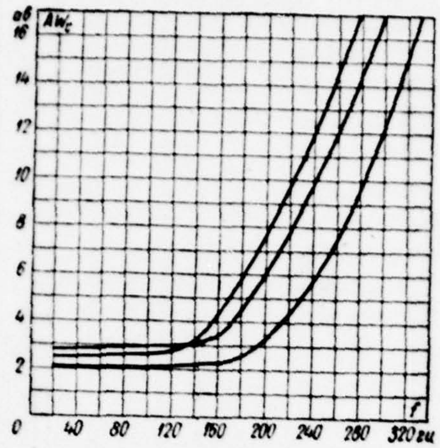

Fig. 14.9. Curved of dependences of ampere-turns of function of relay of type АР-4 on frequency of feeding current.

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The general solution of the obtained nonhomogeneous linear equation will be:

$$\alpha = c_1 e^{nt} + c_2 e^{-nt} - \frac{M_1 I_0}{M_M}. \qquad (14\text{-}30)$$

where

$$n = \sqrt{\frac{M_M}{J}}.$$

From initial conditions we have with t = 0 greatest angle of deflection $a = -\alpha_0$ and speed of motion da/dt =

0; consequently, $c_1 = c_2$ and $2c_1 = \left(\frac{M_i I_0}{M_м \alpha_0} - 1\right)\alpha_0$. Substituting in equation (14-30), we obtain:

$$\alpha = \alpha_0\left[\left(\frac{M_i I_0}{M_м \alpha_0} - 1\right)\operatorname{ch} nt - \frac{M_i I_0}{M_м \alpha_0}\right]. \tag{14-31}$$

The maximum value of the angle of deflection of armature will occur through the time $t_{дв}$:

$$\alpha_0 = \alpha_0\left[\left(\frac{M_i I_0}{M_м \alpha_0} - 1\right)\operatorname{ch} nt_{дв} - \frac{M_i I_0}{M_м \alpha_0}\right],$$

whence we find expression for the time of the motion of the armature of the relay

$$t_{дв} = \frac{1}{n}\operatorname{arcch}\frac{\frac{M_i I_0}{M_м \alpha_0} + 1}{\frac{M_i I_0}{M_м \alpha_0} - 1} = \frac{2}{n}\operatorname{arcth}\sqrt{\frac{M_м \alpha_0}{M_i I_0}}. \tag{14-32}$$

If the torque/moment, created by conservative value of control current, is much more the torque/moment, created by the direct flow, then approximately it is possible to count:

$$\operatorname{arcth}\sqrt{\frac{M_м \alpha_0}{M_i I_0}} \approx \sqrt{\frac{M_м \alpha_0}{M_i I_0}}.$$

Substituting in equation (14-32) instead of n its value, we obtain:

$$t_{дв} \approx 2\sqrt{\frac{J}{M_м}}\sqrt{\frac{M_м \alpha_0}{M_i I_0}} = 2\sqrt{\frac{J\alpha_0}{M_i I_0}}. \tag{14-33}$$

Consequently, the time of the motion of armature is proportional to square root of the torque/moment of inertia and angle of deflection and it is inversely proportional to square root from the torque/moment, created by control current.

If the current, which passes on the windings of relay, grows in sinusoidal law, then the time of the motion of the armature of the relay

$$t_{\text{дв}} = 2{,}3\sqrt{\frac{\alpha_0 J\left(1+\frac{J\omega^2}{M_{\text{м}}}\right)}{M_1 I_0}}. \tag{14-34}$$

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b) armature with flexible reed.

In relay with flexible reed the angle of deflection of armature is not limited to backstop to contact, since as a result of the sagging/deflection of reed the deviation of armature will be more.

With flexible reed the armature begins to move with elastic force during the cessation of coil current; therefore transient time for relay with flexible reed must be less. Approximately by its it is possible to express

following formula:

$$t_{\text{дв}} = \frac{2\alpha_0 \sqrt{J(b - M_{\text{м}})}}{M_1 I_0}, \qquad (14.35)$$

where b are constant, equal to torque/moment for an angle into one radian and depending on construction and elasticity of reed.

14.5. Vibration of armature.

With the impact against fixed contact, the armature obtains the momentum/impulse/pulse of rotation, equal to:

$$\tau_1 \delta t = J(\omega_1 - \omega_2), \qquad (14.36)$$

where τ_1 - the pulse torque/moment, obtained with impact,

δt - the duration of impact,

J - the moment of the inertia of armature,

ω_1 - the angular velocity from which the reed of armature strikes against fixed contact with the first impact, and

ω_2 - the angular velocity of reed reflected after impact.

The angular velocity

$$\omega_2 = k_B \omega_1, \quad (14\text{-}37)$$

reflected where k_B is a recovery factor whose value depends on the elasticity of the colliding bodies. For steel and platinum

$$k_B = \frac{5}{9}.$$

For simplification, let us assume that during the small deviations of armature its acceleration a will be constant; then the maximum angle of deflection of armature after impact can be determined from the equation:

$$\beta_1 = k_B \omega_1 t - \frac{1}{2} a t^2.$$

During the deviation of armature of the maximum angle of its speed, are equal to zero, i.e., $k_B \omega_1 - at = 0$, whence $t = \frac{k_B \omega_1}{a}$.

Consequently formula for the angle of deflection of armature will take the following form:

$$\beta_1 = \frac{k_B^2 \omega_1^2}{a} - \frac{k_B^2 \omega_1^2}{2a} = \frac{k_B^2 \omega_1^2}{2a}. \quad (14\text{-}38)$$

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With each impact of armature, its speed decreases $k_в$ once; therefore after n of impacts the deviation of the armature

$$\beta_n = k_{\text{в}}^{2n} \frac{\omega_1^2}{2a}. \qquad (14\text{-}39)$$

Thus, with an increase in number n the deviation of armature β_n decreases and approaches zero.

For a decrease in the vibration of armature, it is necessary that the recovery factor will be smallest possible.

The complete elimination of the vibration of armature is achieved by the application/use of a flexible contact stud, which consists of two flat/plane bronze springs whose end/leads 1 are bent and press to each other with force 20-30 g (Fig. 13-4). With the impact against the contacts of spring, they are bent and simultaneously their end/leads are moved according to relation to each other; in this case the large part of the kinetic kinetic energy of armature is absorbed by friction of springs.

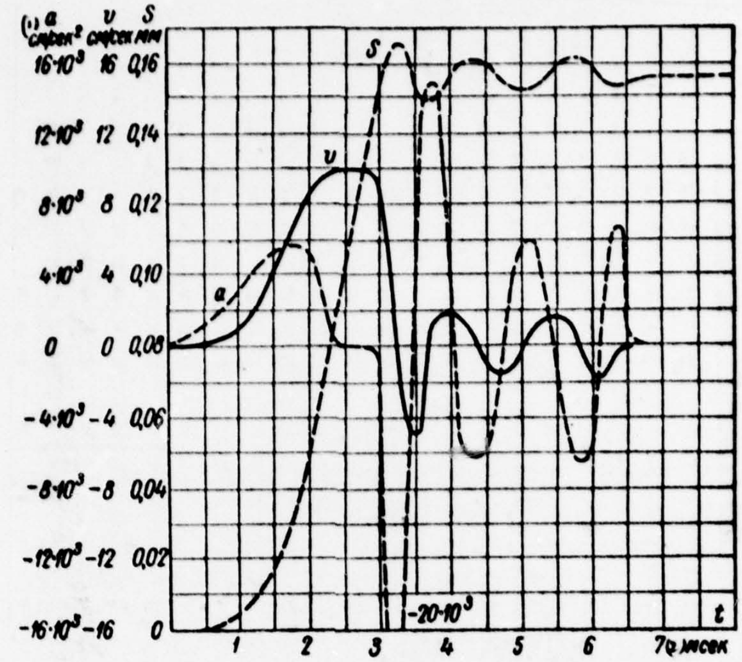

Fig. 14-10. Curved of dependences of displacement/movement, velocity and acceleration of armature of relay of type RP-4 on time ($AW_0 = 1{,}5$ AV and $AW_p = 10$ AV).

Key: (1). cm/s. (2). ms.

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Figures 14-10 gives the curve of the dependence of the armature travel of relay of type RP-4 on time (mechanogram of the motion of armature), obtained by S. L. Khaytser

experimentally with the aid of kinematic camera with AW = 10 AV.

In this same figure are constructed the curves of the dependences of the speed of the motion of armature v and of acceleration a from time, the obtained by graphic differentiation mechanograms.

From the curves of Fig. 14-10, it is possible to easily find the impact velocities and rebound of the armature of relay from fixed contact after impact.

During the nominal excitation, equal to 10 AV, the recovery factor of the armature of relay of type RP-4 is equal approximately 0.62. During a change in the working ampere-turns from 5 to 25, value $k_{в}$ decreases from 0.7 to 0.5.

During the fluctuations of the armature of relay, the current circuit of contacts will not be disruptted, if the amplitude of the disagreement of contacts will not exceed the amount of their strain. The amount of strain at the impact of two spherical contacts (in μ) will be equal [14-1]:

$$\lambda = 0{,}776\sqrt[3]{F^2\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\left(\frac{1}{E_1}+\frac{1}{E_2}\right)^2}\ [\text{мк}], \qquad (14\text{-}40)$$

where F - the acting force in g, R_1 and R_2 - radii of the spheres of the colliding contacts in mm, E_1 and E_2 - modulus of elasticity of the materials of the colliding contacts in g/mm².

If one contact spherical, and another flat/plane and both contacts are made from identical material, then

$$\lambda = 1{,}23\sqrt[3]{\frac{F^2}{RE^2}} = kF^{2/3}. \qquad (14\text{-}41)$$

For the spherical contacts by diameter 2.5 mm from silver or gold value k = 0.028, from platinum k = 0.017, from palladium k = 0.021 and made of tungsten k = 0.0094.

The moment of the inertia of the armature of relay can be easily determined experimentally.

For determining the period of the fluctuations of the armature of relay of the type RP, one of the end/leads of the suspension spring of armature is soldered to the free end/lead of the long, vertically arranged/located bronze wire

whose upper end is rigidly attached.

The period of the torsional oscillations of the armature of relay, fixed toward the end of the wire (to vertical shaft), is equal [redacted]. [2-7]:

$$T = 2\pi \sqrt{\frac{J}{a}} = 2\pi \sqrt{\frac{J32l}{G\pi d^4}},$$

where J - torque/moment of the inertia of armature of relatively suspension spring (rotational axis of armature);

a - a stiffness coefficient of wire (shaft);

d - a diameter of the section of wire;

l - its length;

G - modulus of shear of the material of wire during twisting.

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We will hence obtain for the moment of the inertia of the armature of relay the following expression:

$$J = \frac{Gd^4T^2}{128\pi l}. \qquad (14\text{-}42)$$

The period of the torsional oscillaticns of the armature of relay of the type RP, soldered to bronze wire by diameter 0.11 mm and by length 255 mm, during measurement will prove to be equal to 2.0 s. For bronze G = 4.8 x 10⁶ g/mm². Substituting these values in formula (14-42), we will obtain for the armature of relay of the type RP:

$$J = 0.027\ g\cdot mm\cdot s^2.$$

14.6. Graphic method of timing of function.

Triggering time of polar relays, just as electromagnetic nonpolarized (neutral) relays, it depends on the constant value of time, safety factor on ampere turns and the time of the motion of armature.

For determining the inductance of polar relays Fig. 14-11 gives the curves of the dependences of coefficient K (given inductance) on working ampere-turns for the relay of

types TRM, RP and TRL with direct current and alternating current by frequency 50 Hz.

From these curves it follows that a relay of the type TRM has considerably smaller inductance, than as the relay of types RP and TRL. Is explained this by a small section of air gap (the cross section of poles).

For the selection of the optimum values of the safety factor on ampere-turns Fig. 14-12 gives the curves of the dependences of the time delay of types TRM, RP-4 and TRL on the coefficient of reserve K_1 at constant values of the derived power.

From these curves it follows that the advantageous value of the coefficient of reserve on ampere-turns of relay of the type TRM is within the limits from 2.2 to 5, of relay of type RP-4 - within limits from 5 to 12 and of relay of the type TRL - from 9 to 18.

Time for motion to start reaches the minimum with somewhat the smaller values of the safety factor.

The time of the flight/passage of the armature of

relay of the type TRM does not have clearly expressed minimum; with an increase in the safety factor more than four time of flight/passage barely changes.

For determining the tentative values of triggering time and contact/start of polar relays Fig. 14-13 gives the curves of the dependences of triggering time and of the time for motion to start of relay of the type TRM on the value of coefficient m, with the coefficients of reserve K_1 = 3, and of the time delay of types RP-4, RP-5 and RP-7 with K_1 = 5.

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The time of the motion of armature (time of flight/passage) of polar relay is comparatively great and it is commensurable with time for motion to start; therefore the curves of the time delay at the different values of working ampere-turns give the smaller errors during, than curved ones of triggering time of these relays at the different values of the safety factor on ampere-turns.

Figures 14-14 and 14-15 gives the curves of the dependences of triggering time on the amount of power input at the different values of working ampere-turns for the relay of types TRM, RP-4, RP-7 and TRL.

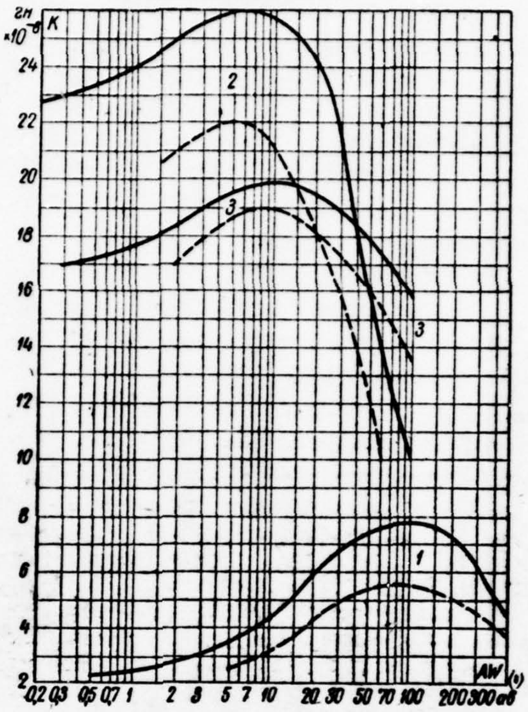

Fig. 14-11. Curved of dependences of coefficient K on working ampere-turns; solid lines - with direct current; broken - with alternating current - 50 Hz. 1 - relay of the type TRM; 2 - relay of the type RP; 3 - relay of the type TRL.

Key: (1). AV.

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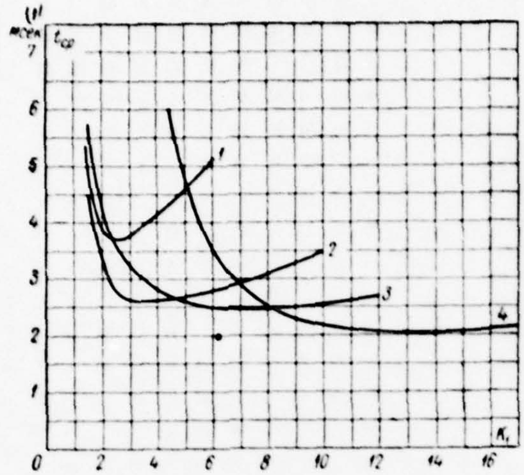

Fig. 14-12. Curved of dependences of time delay on safety factor on ampere-turns with constant value of power input. 1 - type TRM, P = 0.5 W; 2 - type TRM, P = 2 W; 3 - type RP-4, P = 0.05 W; 4 - type TRL, P = 0.05 W.

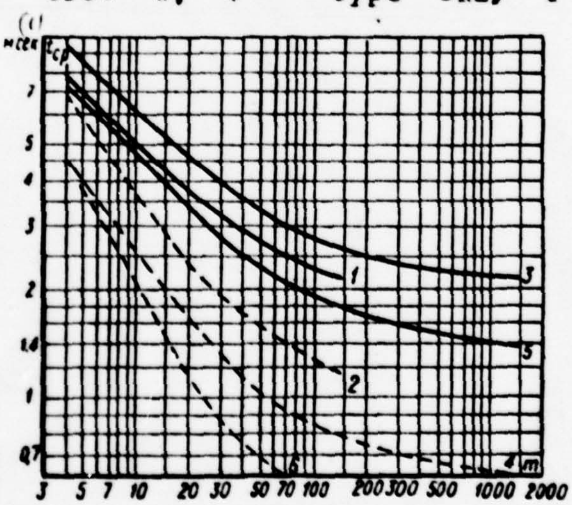

Fig. 14-13. Curved of triggering time of polar relays. 1 - relay of the type TRM, K_1 = 3 (function); 2 - relay of the type TRM (contact/start); 3 - relay of type RP-4 and

RP-5, K_1 = 5 (function); 4 - relay of type RP-7, K_1 = 5 (function); 6 - relay of type RP-7 (contact/start).

Key: (1). ms.

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The time delay of type RP-4 during a change of the excitation of winding within limits from 5 to 25 AV (change in the value of the coefficient of reserve K_1 approximately from 2 to 10) can be expressed approximation empirical formulas: within the limits of a change of the values of coefficient of m from 8 to 60

$$t_{cp} \approx \frac{130}{\sqrt{m}\sqrt{AW^3}} \text{ [ms]} \quad (14\text{-}43a)$$

within the limits of values m from 20 to 200

$$t'_{cp} \approx \frac{76}{\sqrt[3]{m}\sqrt[4]{AW^3}}. \quad (14\text{-}43b)$$

The time for motion to start (function of the breaking contact) of relay of type RP-4 with AW = 5-25 AV within the limits of values m from 8 to 200

$$t_{rp} \approx \frac{42,5}{\sqrt{m}\sqrt{AW^3}}. \quad (14\text{-}43c)$$

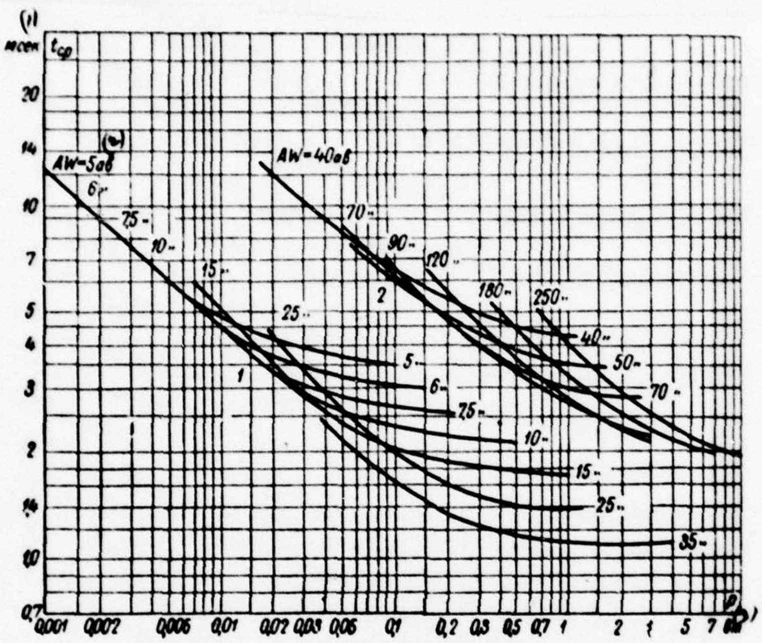

Fig 14.14. Caption next page.

Fig. 14-14. Curved of dependences of triggering time of polar relays on value consumed power. 1 - type RP-4; 2 - type TRM.

Key: (1). ms. (2). AV. (3). W/

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The time delay of type RP-7 during a change of the excitation of winding within limits from 10 to 25 AV (K_1 = 2-5) and changes in value m from 3 to 50, and also during change AW from 25 to 50 (K_1 = 5-10) and value m from 3 to 25, will be equal to:

$$t_{cp} \approx \frac{575}{AW\sqrt[5]{m^2}} \text{ [ms]} \qquad (14\text{-}44a)$$

a within the limits of values m from 10 to 200-100, with AW = 10-25 AV and values m from 5 to 100-50, with AW = 25-50 AV

$$t'_{cp} \approx \frac{380}{AW\sqrt{m}}. \qquad (14\text{-}44b)$$

The time for motion to start of relay of type RP-7 during a change in the ampere-turns from 10 to 50 (K_1 =

3-10) and values m from 3 to 40-20

$$t_{\text{тр}} \approx \frac{625}{AW \cdot m}. \quad (14\text{-}44a)$$

The value of coefficient C_m for relay of the type RP is equal to $C_m = 4{,}25 \cdot 10^{-6}$ to ohm.

The releasing time of relay of type RP-7 is within the limits from 1.8 to 2.8 ms for the breaking contact and from 0.7 to 1.3 ms for circuit closing contacts.

With the shorting of the winding, which has $C_н = 10 \cdot 10^{-6}$ ohm, the releasing time of relay RP-7 during excitation to 35 AV is equal to $t_{он} = 100 \div 200$ to ms, while during larger excitation to 130-260 ms.

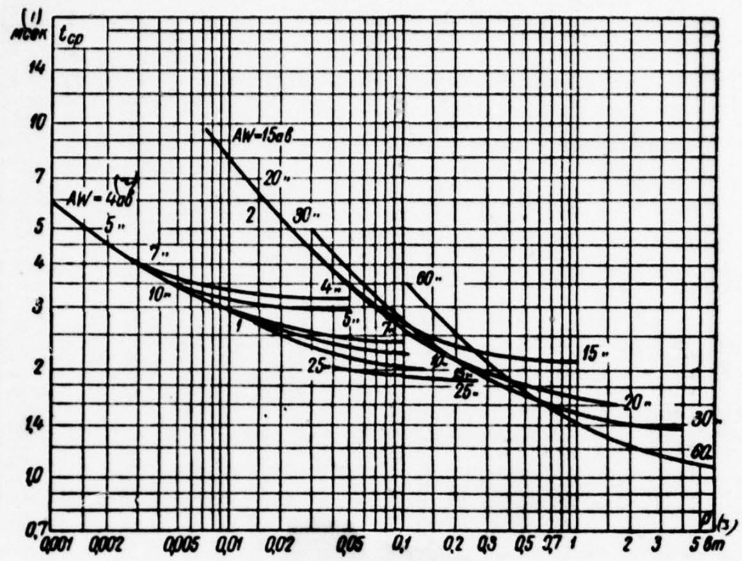

Fig. 14-15. Curved of dependences of triggering time of polarized relays on amount of required power. 1 - type TRL; 2 - type RP-7.

Key: (1). ms. (2). AV. (3). W.

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Time of triggering of relay of the type TRM during the supplying into its winding from 75 to 400 AV (K_1 = 1.8-10) and changes in value m from 6 tc 150+50:

$$t_{cp} \approx \frac{285}{\sqrt[8]{m \cdot AW^2}}, \qquad (14\text{-}45)$$

while the time for motion to start of this relay

$$t_{\text{тр}} \approx \frac{137}{\sqrt{m \cdot AW}}. \qquad (14\text{-}45a)$$

Value C_m for relay of the type TRM is equal to $C_m = 2{,}15 \cdot 10^{-6}$ ohm (for each coil $C_m = 4{,}3 \cdot 10^{-6}$ ohm).

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Chapter Fifteen

MAGNETOELECTRIC RELAY.

15.1. Cell/elements of calculation of magnitoelectric relays.

Magnitoelectric they are called the relays whose action is based on interaction of the current, which takes place on winding, with the magnetic field of the permanent magnet. These relays react both to the value and to direction of flow in their winding.

Magnitoelectric relays have very high sensitivity. They are manufactured to spill currents from 0.6 μA and is above (power of function from 10^{-10} W). In this case, their controlled power usually is within the limits from 0.1 to 2 W. One of the deficiency/lacks in these relays is relatively long triggering time - from 0.01 to 0.5-2 s.

Magnitoelectric relay is actually the measuring meter of magnitoelectric system, on framework of which instead of the indicator (rifleman/gunners) is fastened the lever with slide contact. On the insulating block, strengthened on the housing (panel) of the relay are installed two fixed contacts between which is moved the slide contact. Turning moment, created by current through the winding by the relay taking place (framework), is determined by the following expression:

$$M_{\text{в}}=\frac{BSwI}{9810}\cdot 10^4\approx BSIw\;[\Gamma\cdot c\text{м}], \qquad (15\text{-}1)$$

where B - magnetic induction in working gap in T, S - an active area of the framework in cm², w - a turn number of the winding of the framework even I - a current in a.

For the function of relay, it is necessary that turning moment will be more than the sum of all torque/moments, counteracting to the motion of the framework. During the motion of the framework of relay turning moment oppose the moment of frictional force $M_{\text{тр}}$ and the reactionary torque of return moment springs $M_{\text{пр}}$. The moment of frictional force

$$M_{\text{тр}}=\mu g_{\text{п}} r_{\text{к}}, \qquad (15\text{-}2)$$

where μ is the coefficient of friction, $g_м$ - the weight of the movable system of relay in g and $r_к$ - a radius of the area/site of the contact of core in cm, i.e., a radius of core.

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For a core from carbon steel and step bearing from agate the coefficient of friction $\mu \approx 0.13$ [L. 15-1].

Reactionary torque of the springs

where W is the specific reactionary torque in g•cm through radian and α - the angle of rotation of the movable system of relay in radians.

Unlike usual measuring meters, relay, besides the rotation of movable system through certain angle, must fulfill the supplementary mechanical work, necessary for the creation (or disturbance/breakdown) of the electrical contact of the controlled electrical circuit. The value of supplementary torque/moment during function $M_{д1}$ is determined by that minimum pressure in contacts, which it is necessary

for the destruction of the nonconducting films, which are instantly formed on the surface of any contact material in air. The value of supplementary torque/moment at release/tempering $M_{пз}$ is determined by that minimum effort/force which is required for the disconnection of contacts, i.e., for the overcoming of the forces of molecular cohesion/coupling, forces of electrostatic attraction and disruption of the microscopic liquid bridges which are formed between contacts during interrupting of electric current.

It is obvious that the value of supplementary torque/moment $M_{п}$ is not constant, but it depends on a number of factors, somehow: size/dimensions, forms and the material of contacts, state of their surface, environmental conditions (composition of the atmosphere, its temperature and humidities) and of the parameters of the switched by contacts circuit (stress level, current, kind and type of load).

In the case of the ideal balance of movable system during function, electrical turning moment must be equal to:

$$M_{э\,ср} = M_{с} + M_{тр} + M_{п1},$$

a with the release/tempering

$$M_{\text{э отп}} = M_{\text{в}} - M_{\text{тр}} - M_{\text{к0}}.$$

Let us examine the case of magnitoelectric relay with the stud switch when slide contact in the absence of current is closed with one of the fixed contacts.

At the initial moment in the absence of coil current, the slide contact is pressed against moticnless with force f_0, and the torque/moment of the contact pressure, created by the twisting of moment springs on angle α_0,

$$M_{\text{к0}} = f_0 l, \tag{15-4}$$

where l is a distance of contact from the axis of rotation.

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So that these contacts will be disconnectted, it is necessary that electrical turning moment $M_{\text{э1}}$ will be more than the sum of the torque/moments, created by contact pressure, bearing friction of rotation and by supplementary effort/force, were necessary for the disconnection of the locked contacts, i.e.,

$$M_{э1} \geqslant M_{а0} + M_{тр} + M_{д2}, \qquad (15\text{-}5)$$

where $M_{д2}$ is the torque/moment, necessary for the disconnection of contacts.

Electrical turning moment, necessary for the closing/shorting of opposite contact and creation in it of the necessary contact pressure, obviously, will be:

$$M_{э2} \geqslant M_{э1} + M_{а} + M_{д1} \geqslant M_{а0} + M_{тр} + M_{д2} + M_{а} + M_{д1}, \qquad (15\text{-}6)$$

where $M_{д1}$ - the torque/moment, necessary for the creation of the minimally permissible contact pressure.

During reduction in current in the winding of the framework, the contacts are broken under condition when

$$M_{вот} \leqslant M_{а} + M_{а0} - M_{тр} - M_{д2}. \qquad (15\text{-}7)$$

For return of slide contact to initial position and the closing/shorting of resting contact with the disconnection of current within the framework, it is necessary that the torque/moment $M_{а0}$ will be more than moment of friction

$$M_{а0} > M_{тр}.$$

The relay reset coefficient, obviously, can be expressed by the following formula:

$$k_{в} = \frac{M_{вот}}{M_{в2}} = \frac{M_{e} + M_{в0} - M_{тр} - M_{д2}}{M_{e} + M_{в0} + M_{тр} + M_{д2} + M_{д1}}. \qquad (15\text{-}8)$$

The great possible value of resetting ratio will occur in the ideal case when $M_{д2} = 0$ and $M_{в0} = M_{тр}$. Then, set/assuming $M_{д1} = M_{в0}$, we will obtain for the maximum value of resetting ratio:

$$k_{в\,макс} = \frac{M_{e}}{M_{e} + 3M_{тр}}. \qquad (15\text{-}8a)$$

Consequently, the value of the relay reset coefficient increases with an increase in the reactionary torque of springs and reduction in the weight of movable system.

If the small permissible pressure in contacts is taken as equal to f_0 = 20 mG and distance l = 5 mm, then is initial moment $M_{в0} = 20 \cdot 0{,}5 = 10$ mG•cm. Set/assuming $r_{к} = 20$ mm and $g_{п} = 2{,}5$ g, we will obtain:

$$M_{тр} = 0{,}13 \cdot 20 \cdot 10^{-4} \cdot 2{,}5 = 0{,}65 \quad \text{mG•cm.}$$

With the value of reactionary torque 150 ~~mG~~ mg•cm,

accepting $M_{\text{м}} = 7$ mg•cm and $M_{\text{м}} = M_{\text{э}}$, we will obtain:

$$k_{\text{в}} = \frac{150 + 10 - 0,65 - 7}{150 + 10 + 0,65 + 10 + 7} = 0,9.$$

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If we decrease the reactionary torque to 10 mg cm, then resetting ratio will be equal to 0.326.

The time delay depends on the safety factor on the spill current and values of the resistor/resistance for which is locked the framework.

On value of this resistor/resistance depends the oscillatory or aperiodic state of motion of the movable system of relay. The external critical resistor/resistance, during which oscillatory state of motion changes to aperiodic, approximately can be determined by the formula:

$$R_{\text{вн. кр}} = \frac{2B^2S^2w^2}{10^3\sqrt{JM}} - r, \qquad (15\text{-}9)$$

where B - magnetic induction in working gap in ml, S - an area of the framework in cm², w - a turn number, J - the moment of the inertia of the movable system of relay in cm⁴, M - reactionary torque of spring in g•cm 90° and r - winding impedance of relay.

Calculation of magnetic system of relay with inner frame magnet.

The most advantageous magnetic system for a magnitoelectric relay is the system with inner frame magnet, depicted in Fig. by 15-1, since it has small scattering.

Magnetic induction in the working gap of system is nonuniform and it reaches maximum in the direction of the axis of magnetization.

For the determination of the law of induction distribution in gap is permissible that the field of magnet is uniform, and let us isolate elementary layer by thickness d. The direction of field in gap is perpendicular to the surface of magnet and cylindrical framework.

The operating point of magnetic system is determined from demagnetization curve with the aid of angular coefficient (§ 4-16)

$$\operatorname{tg}\gamma = \frac{l}{q}\cdot\frac{m_H}{R_\delta m_B} = \frac{D\sin\varphi\cdot m_H}{dh\frac{2\delta}{dh}\sin\varphi\cdot m_B} = \frac{Dm_H}{2\delta m_B} = \frac{rm_H}{\delta m_B}, \quad (15\text{-}11)$$

where m_B and m_H are scale factors.

Consequently, magnetic induction in all sections of magnet is identical and does not depend on angle ϕ.

Gap density

$$B = B_0\frac{q}{S}k = B_0 k\sin\varphi, \quad (15\text{-}12)$$

where B_0 is magnetic induction of magnet and k - the coefficient of the use of a magnetic system (k = 0.5-0.8).

Thus, in gap magnetic induction is distributed according to the law of sine; at small angles it is possible to count the induction of uniform.

15-2. Magnitoelectric relay of type ~~RMD~~ RME-2.

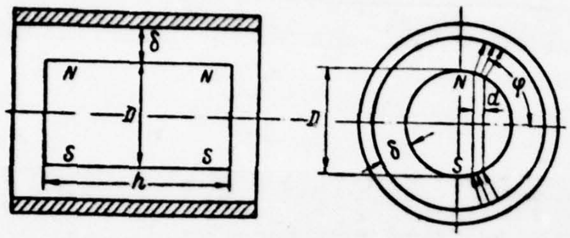

Fig. 15-1. Magnetic system with inner frame magnet.

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Average length of layer l = D sin φ, where D, the diameter of magnet,. The cross-sectional area of layer q = dh, where h - the height/altitude of magnet,

$$\sin\varphi = \frac{S_E}{S_L},$$

where S_E is the cross section of magnet and S_L - the cross section of air gap.

Surface area S through which emerges the magnetic flux of layer,

$$S = \frac{dh}{\sin\varphi}.$$

The resistor/resistance of the gap, limited by surface of S,

$$R_\delta = \frac{2\delta}{S} = \frac{2\delta}{dh}\sin\varphi, \quad (15\text{-}10)$$

where δ is length of air gap.

Magnitoelectric a burdock of type RME-2, developed T. K. Shtremberg, is intended for the automatic adjustment of transmission level in equipment for long-distance communication.

Relay can be operated during changes in the temperature of surrounding air from 0 to +40°C and relative humidity 65 ± 15o/o.

The general view of relay of type RME-2 is shown in Fig. 15-2.

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Relay has one stud switch. The magnetic system of relay consists of right-angled (framework) magnetic circuit (31 x 37 x of 38 mm) within which on twc holders from aluminum fusion with zinc is fastened inner frame magnet from alloy anko-4 with the poles of cylindrical form. Size/dimensions of magnet 17 x 29.5 x 28 mm (diameter of machining - 29.5 mm), weight - 90 g.

In the radial magnet gaps and by framework rotates movable system - the aluminum framework with winding and

two internal steel cores. Magnetic induction in working gap 0.4 ml. Active section of the framework 8.7 cm². Step bearings are fastened on the holders of those who were screwed on to framework. The winding of the framework has 1000 turns of wire as a diameter 0.04 mm (PEL). Winding impedance of the framework 1850 ohm. Weight of the framework with the winding 2.5 g. The supply of current to the winding of the framework is realized with the aid of the annealed tapes by thickness 4-5 μ with the negligibly small reactionary torque. On top on movable system is stuck holder with the two-way slide contact of cone-shaped form. Distance of contact from rotational axis 5 mm.

Fixed contacts - flat/plane, by diameter 3 mm; they are establish/installed on two contact springs which are fastened on the holders, screwed on to end-type block from plastic. Contacts are made from palladium fusion with silver (40o/o).

The recurrent torque/moment of relay is created by the helical spring whose internal end/lead is soldered to the holder of slide contact, and external - to the movable (adjusted) current distributing spring, establish/installed on block. Torque/moment of spring 180 mg•cm during the rotation

of the framework through 2.5° (6500 mg•cm - through 90°).

The movable current distributing spring has a gash, which makes it possible for it to be moved on circular arc and to twist helical spring to certain angle.

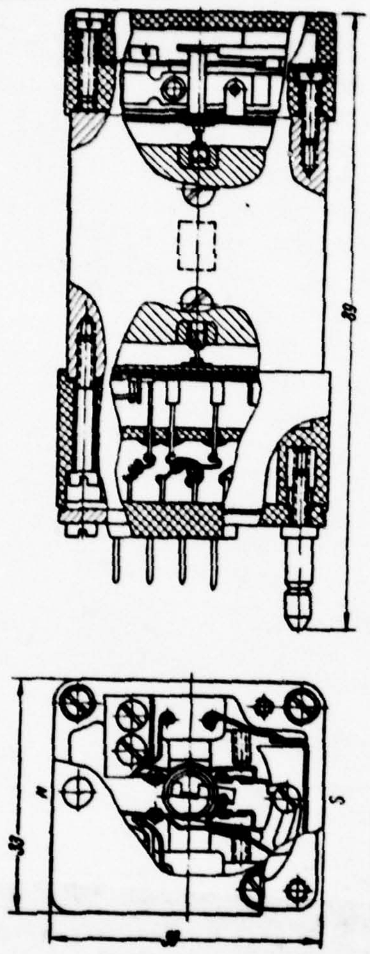

Fig. 15-2. Relays of type RME-2.

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So that the relay could note the current variations in winding of relatively certain value (0.5-1 mA), corresponding to the datum level of control current I_{cp}, the movable

system of relay must at this value of current be located in the mid-position. This is reached by the twisting of return spring to the angle, which corresponds to the nominal value of control current.

The distance among contacts is more than 2 x 0.2 mm. The sensitivity control of relay is realized by two adjusting screws, which make it possible to move springs with "fixed contacts".

Relays are manufactured at the nominal values of the control current: 0.1-0.125-0.26-1.05 and 1.1 mA react to changes in current ±50 (±100) μA and power ±4.6 μW. Error in the spill current because of variation ±10 μA.

Relay for a control current 0.1 mA breaks n.z. contacts with current not more than 62 μA and closes them with current not less than 54 μA, and n.r. contacts are closed with current not more than 146 μA and are broken with current not less than 138 μA. Relay reset coefficient 0.87-0.945.

Relay for a control current 1.05 mA breaks n.z. contacts with current not more than 1.016 mA and closes

them with current not less than 1.004 mA, and n.r. contacts are closed with current not more than 1.096 mA and are broken with current not less than 1.084 mA. Relay reset coefficient 0.99.

To avoid victuals of the contacts of relay, must switch resistive load not more than 16 mA with voltage 24 V in (0.38 W) direct current. During the use of an inductive load, for example the winding of relay of the type RPN, the latter must be shunted by effective resistance 3000 ohm.

Service life of the relay of 10^5 cycles. Triggering time is comparatively great. Figures 15-3 gives the curves of the dependences of the time delay of type ~~RMS~~ RME-2 on the value of coil current at the different adjustment of relay and the different values of supplementary external resistor/resistances (R = 0 and R = 10000 ohm).

Of relay without the preliminary twisting of return spring (during neutral adjustment) with dual reserve on spill current (I = 100 μA) and supplementary resistor/resistance 20000 ohm triggering time is equal to 130 ms. With current 250 μA (K_1 = 5) triggering time

decreases to 50 ms, while with current 500 μA - to 30 ms.

The time delay depends also on the angle of the preliminary twisting of return spring. The recurrence time of relay to the contact of rest with the disconnection of the current of the mid-position I_{op} depends on the value of this current, i.e., on the angle of twist of spring.

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With $I_{op} = 1{,}05$ mA the recurrence time of the contact of relay is 8-10 ms. Insulation of winding and contacts of relay is maintain/withstood 500 V eff. Electrical insulation resistance is more than 100 MΩ.

Conclusion/derivations from winding and the contacts of relay of type RME-2 are conducted to a plug cut-in block of type RP-4, fixed to the lower end/face of framework. The upper end-type block of relay with contact system is closed by cap/cover from plastic. In appearance of relay of type RME-2, it is similar to a polar relay of type RP-4. Overall dimensions: 33 x 39 x 76 mm (taking into account the length of the current-carrying knives and plugs of

attachment - 33 x 39 x 89 mm). Weight of relay 300 g.

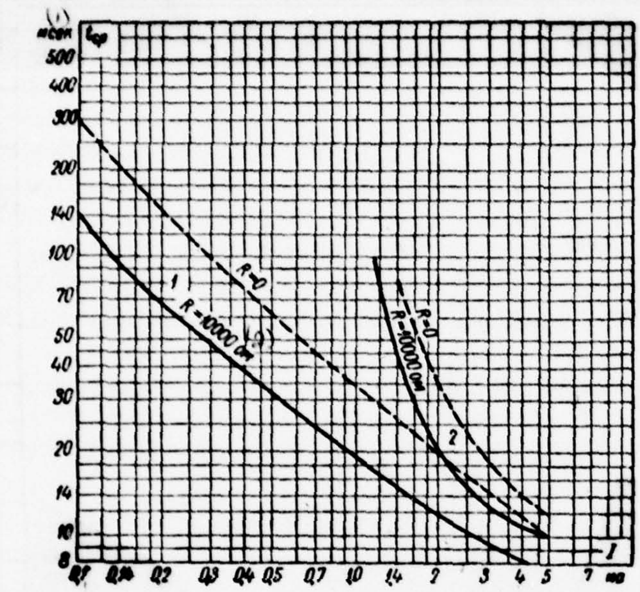

Fig. 15-3. Curved of dependences of time delay of type RME-2 on coil current. 1 - the neutral adjustment of relay $I_{средн} = 0$; 2 - the value of control current $I_{средн} = 1,05$ mA.

Key: (1). ms. (2). ohm.

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15.3.

Magnitoelectric relay of types M201, M202, M219 and M225.

The magnitoelectric relays of types M201, M202, M219 and M225 are intended for a direct work from the primary sensors of very small power (photocells, piezoelectric cells, induction converters and of the like).

These relays can be operated during changes in the temperature of surrounding air from -40 to +50°C and relative humidity to 80o/o, and also with relative humidity to 98o/o at temperatures from 5 to 20°C.

The general view of relay is shown in Fig. 15-4. The relays of types M201 and M202 have cylindrical form; the diameter of relay 51 mm, length 60 mm; the weight of relay is not more than 350 g.

These relays have magnetic system with two external magnets, arrange/located within framework.

Movable winding is wound around the open aluminum framework; winding impedance 200, 850 or by 1700 ohm ±(15-20)o/o.

Relays have one stud switch. Contacts are wires from the alloy of brand plI-10 by diameter 0.15 mm, which

intersect at right angles.

Slide contact is fastened on the framework, and motionless on insulating block. Recurrent torque/moment is created by two helical springs. The adjustment of fixed contacts is realized with the aid of two adjusting screws.

The construction of the relay of types M201 and M202 is identical. The slide contact of relay of the type M201 has common point with the winding of the framework, the contact system of relay of the type M202 is isolate/insulated from winding.

The power, necessary for the function of the relay of different performances, is within the limits from $0.8 \cdot 10^{-10}$ to $1.2 \cdot 10^{-7}$ W. Spill current of relay from 0.6 to 26 μA, the instability of spill current $\pm(7-15)$ o/o.

Due to a comparatively low value of reactionary torque (from 0.13 to 5 mg•cm) the relay reset coefficient is very low.

For the exception/elimination of the possibility of scaling of the contacts of the relay with of the

disconnection of current in its winding, it is necessary after closing of contacts to short-term increase current within the framework to 50-200 μA or tax into the circuit of the framework the current pulses of opposite direction.

With an increase of the current within the framework to 50-200 μA, the fixed contact caves in, and after the disconnection of circuital current of the framework, this contact is straighten/rectified and reject/throws slide contact to initial position.

Period of the free fluctuations of the movable system of relay of approximately 1.2 s. External critical resistor/resistance approximately from 5000 to 30000 ohm.

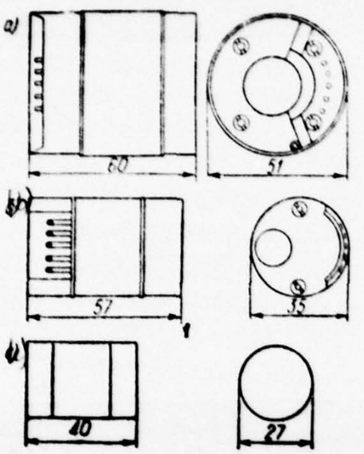

Fig. 15-4. Magnitoelectric relays: a) types M201, M202; b) type M219; c) type M225.

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With the shunting of the winding of relay by the resistor/resistance whose value is lower than critical, and the safety factor on spill current, equal to 1.3, the time delay is equal approximately to 5-6 s.

The maximum value of circuital current contactor 0.15a, voltage on dead contacts it is desirable to have not less than 9 v and not more than 35 v.

The service life of contacts with resistive load 0.15 a are 35 in is not less $2 \cdot 10^5$ functions.

Sealing/pressurization is realized by the sealing rubber rings as drying agent it is used silica gel.

A relay of the type M219 has smaller overall dimensions. the diameter of relay 35 mm length 57 mm. Weight of approximately 100 g.

Relay has magnetic system with inner frame magnet and one stud switch.

Contacts are made from the alloy of gold, palladium and platinum.

The power of the function of relay is within the limits from $4 \cdot 10^{-9}$ to $7 \cdot 10^{-7}$ W, spill current is from 1.2 to 30 μA. Winding impedance 500, 800 or by 2000 ohm.

A relay of the type M219 is manufactured in two modifications: with the winding, isolate/insulated from slide contact, and which has common point with this contact.

The smallest overall dimensions it has relay of the type M225. The diameter of this relay is equal to 27 mm, length 40 mm, weight does not exceed 40 g.

Power of the function of relay about $2.5 \cdot 10^{-6}$ W. Relay has two independent windings and one stud switches.

Load, switched by contacts, and the period of their service the same as in the relay of types M201, M202 and M219.

A relay of the type M225 has airtight metal housing, conclusion/derivations are realized through the glass base.

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Chapter Sixteen

RELAY FOR THE COMMUTATION OF THE CIRCUITS OF HIGH FREQUENCY.

16-1. General information.

For the commutation of the circuits of high frequency, are applied electromagnetic relays with special contact system ("high-frequency relays"), that has small electrical the capacitance/capacity between dead contacts, high electrical insulation resistance and low dielectric losses in the circuit of contacts.

The windings of high-frequency relays are usually supplied from the grid/network of direct current or alternating current by frequency 50 Hz. The contact system of high-frequency relays is collect/built on the basis, prepared from high-frequency ceramics, high-frequency plastic

or glass.

In the case when is required very high insulation resistance, the contact system of relay is insulated by amber, polychlorotrifluoroethylene or polystyrene.

For a decrease in the capacitance/capacity between contacts, the contact springs have small size/dimensions and are arrange/located at an angle of approximately 45, 90 or 180° relative to each other. In the latter case the circuit of contacts has the smallest inductance.

With an increase in the diameter of its wire inductance decreases. Flat springs have smaller inductance than wire.

A decrease in the capacitance/capacity of contact system relative to housing is achieved by an increase in the distance of contact springs from the current-carrying and grounded parts of the relay or by the shadowing of the circuit of contacts.

For the commutation of circuits with the frequency of more than 100 MHz, are applied the so-called coaxial relays

- the electromagnetic relays whose contact system is included into cylindrical screen. With the well urged couplings coaxial relays can be applied at frequencies to 500-5000 MHz.

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The contact springs of coaxial relay have largely flat/plane section, the end/leads of the springs and screen conclude with high-frequency couplings for the inclusion into the circuit of coaxial cable.

The contacts of high-frequency relays usually are manufactured from the alloys of gold, palladium or platinum. For a commutation with high speeds of high-frequency circuits at low contact pressures, are applied vacuum or gas-filled contacts. Vacuum contacts are applied also for the commutation of the circuits of high voltage and high frequency.

The capacitance/capacity of the contacts of many miniature/small electromagnetic relays is comparatively small, and usual relays frequently are utilized for the commutation of high-frequency circuits.

The capacitance/capacity between the contacts of the normal designs of contact groups (package type) is expressed approximately by the following formula:

$$C_{к} = 1,1 \frac{b}{4\pi}\left(\frac{\varepsilon_{п} l_{п}}{\Delta_{п}} + \frac{\varepsilon l}{\Delta}\right) \text{[pF]} \qquad (16\text{-}1)$$

where b - width of contact spring in cm, l - length of the test section of contact spring in cm, $l_{п}$ - length of insulating plate between springs, Δ - a distance between springs in cm, $\Delta_{п}$ - thickness of separator in cm, ε - a dielectric constant of the environment (for air $\varepsilon = 1$) and $\varepsilon_{п}$ - a dielectric constant of the material of separator (for getinax $\varepsilon_{п} = 4,5$, for plastic $\varepsilon_{п} = 4 \div 6$).

With the location of contact springs into one line, capacitance value between contacts will be equal to:

$$C_{к} = 1,1 \frac{\varepsilon b l_{к}}{4\pi\Delta}, \qquad (16\text{-}2)$$

where $l_{к}$ - length of the overlapped part of contact springs in cm.

The capacitance/capacity between the contact springs of round cross-section (wire springs)

$$C_{к} = 0,0886 \frac{\pi(\varepsilon l + \varepsilon_{п} l_{п})}{\ln \frac{2h}{d}}, \qquad (16\text{-}3)$$

where l_n is length of the part of the spring, pressed into plastic, in cm, ε_n are a dielectric constant of plastic, h - the distance between centers of springs in cm and d - the wire diameter in cm.

Capacitance/capacity between the contact spring of round cross-section and flat/plane housing (screen)

$$C_к = 0{,}0886\,\frac{2\pi(\varepsilon l + \varepsilon_n l_n)}{\ln\frac{4h}{d}}, \qquad (16\text{-}4)$$

where h - the distance between centers of wire and housing (screen).

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In coaxial relay the capacitance/capacity between contact springs to by housing (by screen,) if we disregard the effect of the stand-off insulators due to their small length, will be equal to:

$$C_к = 0{,}0886\,\frac{2\pi\varepsilon l}{\ln D/d}, \qquad (16\text{-}5)$$

where D is an inner diameter of screen in cm.

Wave impedance of coaxial relay with the contact spring of the round cross-section

$$Z = 138\,\frac{\lg D/d}{\sqrt{\varepsilon}}. \qquad (16\text{-}6а)$$

The wave impedance of coaxial relay with the flat/plane contact spring

$$Z = 138 \lg \frac{2D}{b}, \quad (16\text{-}66)$$

where b is width of contact spring in cm.

Table 16-1 gives corrected values of the capacitance/capacity between contact springs, and also between contact springs and housing for the different types of electromagnetic relays.

From data given in this table, it follows that the smallest capacitance/capacity of contact system among nonhigh-frequency relay have relay of types RES8, RES9 and RES-15. It is necessary to note that the slide contact of relay of the type RES10 has connection with housing.

Table 16-1. Capacitance/capacity of contact systems of relay.

(1) Тип реле	(2) Между контактами $C_к$, пф	(3) Между контактами и корпусом $C_к$, пф	(1) Тип реле	(2) Между контактами $C_к$, пф	(3) Между контактами и корпусом $C_к$, пф
РЭВ1	2,2—2,3	2,1—3,0	РПС-4	20—30	21—50
РПВ1/2-26	2,1—2,5	2,3—3,9	РПС20	0,6—1,2	1,2—2,2
К-201	1,5—1,7	1,6—2,3	ТРМ	19—24	—
Язычковое нормальное (4)	0,5—1,0	1,8—4,0	РПН	7,5—7,8	7,6—9,4
			РКН	10—14	12,8—18,0
Язычковое миниатюрное (5)	0,2—0,5	0,7—2,0	РКМ-1	6,0—7,2	7,0—8,0
			РЭС14	2,7—3,6	7,6—7,8
РЭС6	3,4—3,6	5,8—6,1	РКМП	7,9—8,6	7,5—10,0
РЭС7	2,1—2,2	4,2—4,5	РС-13	4,4—5,5	5,5—7,5
РЭС8	0,6—0,8	1,3—2,7	РС-52	4,4—5,5	5,5—7,5
РЭС9	0,9—1,0	1,2—2,8	РМУ	3,7—4,2	4,3—7,0
РЭС10	1,0—1,2	1,5—5,9	РМУГ	5,3—7,0	7,6—9,1
РЭС15	0,8—0,9	1,0—4,1	РДЧГ	7,4—7,6	6,4—16,1
РЭС22	2,6—3,2	3,0—4,6	РПНВ	4,9—5,5	5,4—5,6
РСМ-1	2,4—3,0	2,4—5,5	РЭН17	3,1—3,5	5,2—6,9
РП-4	5,9—6,8	12—26	МКУ-48	3,4—4,0	5,0—6,6

Key: (1). Type of relay. (2). Between contacts. (3). Between contacts and housing. (4). Uvular normal. (5). Uvular miniature.

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16-2. Relays of the type REV1 (RVMU1).

A relay of the type REV2 is intended for the commutation of the circuits of high frequency (7-15 kHz) in

equipment for long-distance communication.

Relay can be operated with temperatures from -60 to +85°C, relative humidity to 98o/o at 20°C, vibrations with frequency 10-50 Hz during acceleration to 3 g and with frequency 50-75 Hz - to 2 g. The general view of relay of the type REV1 is given in Fig. by 16-1.

Magnetic system is analogous to the magnetic system of relay of the type RMU. Diameter of core 8 mm, length 32 mm.

Relay has one stud switch. Contact springs are riveted to base from high-frequency ceramics. This base has stepped form and is fastend to the housing of relay. For a decrease in the capacitance/capacity, the contact springs have L-shaped form and form by themselves rectangle with contacts in one of the angles. Upper contact spring is arrange/located along the diagonal of this rectangle.

The armature of relay is held in initial position by two return springs. At end/lead of one of the levers of armature, is fastened cylindrical bush from ceramics for the transmission of the effort/forces of armature to movable

contact spring.

To the end/leads of the springs, are riveted the contacts from alloy plI-10 by diameter 2 mm. Pressure in the contacts 20-30 g, the gap between the contacts 0.35-0.45 mm. Course of the armature of relay 0.4 mm, the height/altitude of the plug of loosening 0.05 mm. Pressure of return springs 10-12 g. The nominal voltage of winding 24-75 v, consumed power at the moment of function (at unheated winding) and temperature 20°C is equal to 0.62-0.8 W. Power of the function of relay 0.25 W. Greatest permissible continous rating 2 W (at ϑ = 50°C).

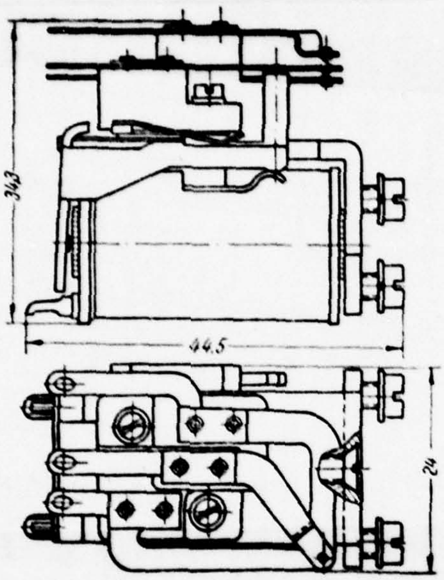

Fig. 16-1. Relays of type REV1.

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In Fig. 16-2 are constructed the curves of the dependences of triggering time and release/tempering of relay of the type REV1 on the amount of power input. From these curves it follows that with nominal voltage triggering time of the circuit closing contacts of relay is equal to 10 ms, and breaking 7 ms. Releasing time is respectively equal to 4.2-5.2 ms.

Capacitance/capacity between the dead contacts 2.2 pF, the greatest capacitance/capacity between contact springs and housing 3.0 pF.

The testing voltage of insulation of winding and contacts 1000 V eff. The electrical insulation resistance of contacts is more than 100 MΩ. Service life of the relay of 10^5 cycles with current 1a-24 V.

Overall dimensions of relay 24 x 34.3 x 44.5 mm, weight 60 g.

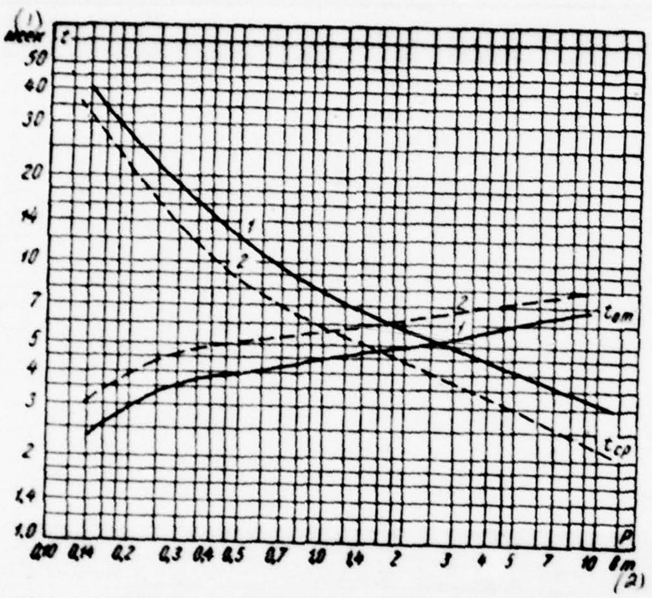

Fig. 16-2. Curved of dependences of triggering time and release/tempering of relay of type REV1 on amount of power input. 1 - circuit closing contact; 2 - breaking contact.

Key: (1). ms. (2). W.

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16-3. Relays of the type RPV1/2-26.

A high-frequency relay of the type RPV1/2-26 is intended for the commutation of circuits high of frequency in miniature/small movable equipment with the fluctuations of temperature from -60 to +80°C, relative humidity to 98o/o at temperature of 20 ± 5°C, with vibration of the places of attachment with frequency 10-70 Hz and acceleration to 4 g and atmospheric pressure to 90 mm Hg.

The general view of relay of the type RPV1/2-26 is shown in Fig. 16-3. The magnetic system of relay is analogous to the magnetic system of relay of the type REV1, but somewhat smaller size/dimensions; the diameter of core 6 mm, length 26 mm.

Armature has on the side elongated lever with ceramic bush at end/lead for displacing the movable contact spring.

Relay is equipped with one stud switch. Contact springs are riveted to base from high-frequency ceramics of stepped form.

For a decrease in the capacitance/capacity, the contact springs are spread and have L-shaped form. To the end/leads of the springs, are riveted single silver contacts.

Course of the armature of relay 1 mm. Pressure in the contacts 15-20 g, the gap between the contacts 0.5 mm. Nominal voltage of winding 27 in direct current, the required power with the unheated winding 1.52 W. Power of function 0.6 W. Greatest permissible contimous rating 2.0 W (at ϑ = 50°C). Capacitance/capacity between the dead contacts 2.5 pF, the greatest capacitance/capacity between contact springs and housing 3.5 pF.

Insulation of contact springs maintain/withstands testing voltage 500 V eff. Service life of the relay of 10^5 cycles.

Overall dimensions: 24 x 29 x 32 mm, weight 42 g.

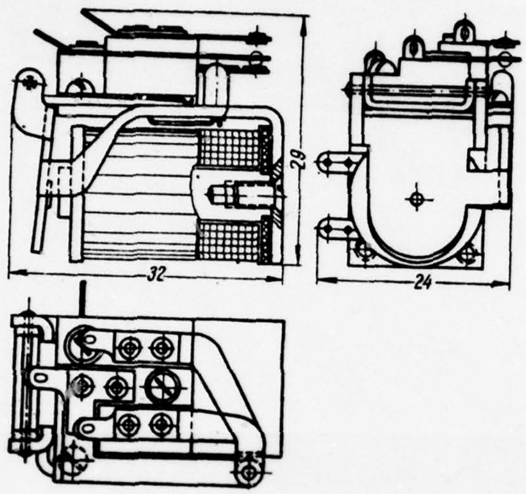

Fig. 16-3. Relays of type RPV1/2-26.

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16-4. Relays of the type K-201.

A relay of the type K-201 is intended for the commutation of the circuits of high frequency (5 MHz) and of the increased voltage in radio equipment. Relays can be operated with temperatures from -60 to +60°C, relative humidity to 98o/o at 20°C, vibrations with frequency 15-18

Hz upon acceleration 1 g and at atmospheric pressure to 144 mm Hg.

The general view of relay of the type K-201 is shown in Fig. 16-4.

The magnetic system of the relay of w-shaped form. Diameter of core 6 mm, length 32 mm. Diameter of the pole piece 9 mm. Relay has one stud switch.

Motionless contact springs are fastened on long cylindrical insulator from radio-ceramics, the screwed on to housing relay. Diameter of insulator 6 mm, overall length 41 mm. Movable contact spring is fastened at the armature of relay and it is isolate/insulated from it by cylindrical insulator by length 5 mm from radio-ceramics. Armature returns to initial position with cylindrical hair spring. To the end/leads of contact springs, are riveted the single silver contacts by diameter 3.5-4 mm.

Course of the armature of relay 0.8 mm, the remanent/residual pole gap and armature 0.4 mm. Pressure in the breaking contact 30 g, in closing 50 g; the gaps between the contacts 1.4-1.6 mm.

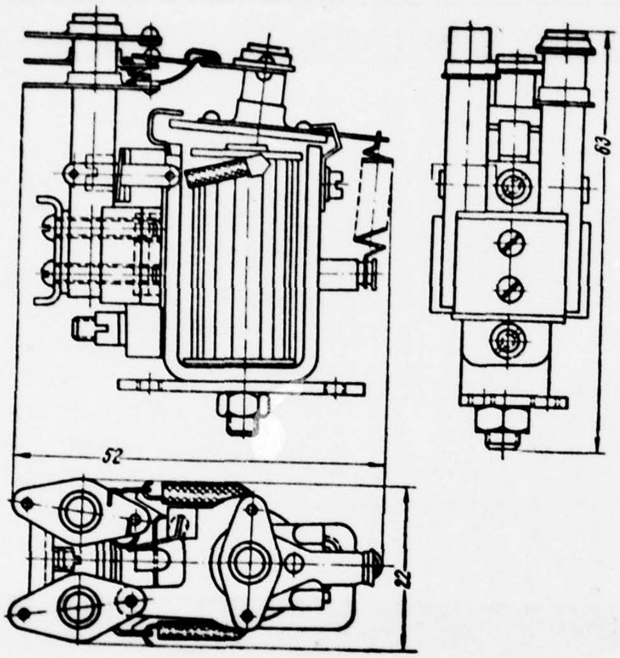

Fig. 16-4. Relays of type K-201.

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Nominal voltage of winding 27.5 v, the required power with the unheated winding 3 W. Power of the function of relay 1.3 W. Greatest permissible continous rating 3.4 W (at θ = 50°C).

The maximum current through the contacts 0.25 a.

The testing voltage of contact system 3200 V eff., windings are 180 V. The electrical insulation resistance of contacts with the increased humidity is not less than 100 MΩ. Service life of the relay $1.5 \cdot 10^4$ of cycles.

Overall dimensions of relay 22 x 52 x 63 mm, weight 85 g.

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Chapter Seventeen

~~ced,~~ Vibrating-reed, mercury and tuned-reeds relay.

17-1. Vibrating-reeds relay.

The short duration failures (failures) of the contacts of electromagnetic relays with light electrical loads usually appear as a result of deposition on the working contact surface of dust, naps, vapors of metals (during soldering and welding), and also under the effect of the effect of different aggressive gases, organic and water vapors, which are contained in the surrounding atmosphere.

For an increase in the reliability of equipment for the automation, working under heavy operating conditions at elevated temperatures and the large relative humidity of ambient medium, are applied hermetically sealed and filled by inert gas the electromagnetic relays whose contacts are

isolate/insulated from environment and are shielded from the incidence/impingement of moisture, dust and dirt.

However, within airtight electromagnetic relay also can be formed the organic and water vapors, isolated during heating by insulation. Furthermore, within relay appears in the course of time dust as a result of the wear of the movable friction parts of the armature, axis, pushers and contacts.

Under the action of organic vapors, gases and vapors of metals on contact surface are formed the films of the polymeric and other connections, which have very high resistor/resistance. These films produce a considerable quantity of short duration failures (failures) of contacts with the commutation of very low currents (μA) and of small voltages (mV).

It is noticed that a great quantity of short duration failures (failures) with the commutation of low currents and voltages is observed in contacts from metals and alloys of platinum group. The application/use of gold contacts sharply decreases a quantity of short duration failures with the commutation of low currents, but it does not eliminate them

completely as a result of the presence of organic vapors, different gases, dust and wear products of the mobile friction parts of the relay (see § 18-8).

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In 1938 in the USA, was developed the magneto controlled circuit closing contact, consisting of two flat springs, hermetically soldered in glass tank/balloon. This contact is sometimes called also hercon (reduction in the words "airtight contact") or uvular switch.

The magneto controlled contact (in abbreviated form μ) consists of glass and metal, it does not contain organic materials and aggressive gases, do not have rubbing parts and it is filled by dry inert gas. This makes it possible to degas the magneto controlled contact at high temperature (to 400°C) and to burn organic films on contact surface.

Vibrating-reed relay is the coil (solenoid), within which it is arrange/located one or several magneto controlled contacts. This relay is characterized by high reliability, small and stable in the value contact resistance, very larger service life (more than 10^7

functions) at the light loads of contacts (less than 4 and 15 W respectively), by smaller triggering time and release/temperings, by the low power of function and by simpler construction in comparison with airtight electromagnetic relays.

Reliability of vibrating-reeds relay by of one-two order higher reliability airtight electromagnetic relays. Failure rate is within the limits approximately from $5\cdot10^{-8}$ to $5\cdot10^{-10}$ failures for one commutation, and airtight electromagnetic relay are from $1\cdot10^{-6}$ to $1\cdot10^{-8}$ failures for one commutation.

According to data given in the prospecti of many foreign firms, the maximum value of the contact resistance of airtight electromagnetic relays at the commutation of very low currents and small voltages can sometimes reach to 300-1200 ohm.

Because of the absence of organic films the resistor/resistance of the magneto controlled contacts considerably more stable; it is within the limits approximately from 0.03 to 0.1-0.2 ohm, in the process of the commutation of very low currents and voltages of up to

$5 \cdot 10^7 - 2 \cdot 10^8$ functions, the maximum value of contact resistance does not usually exceed 2-5 ohm.

Triggering time and release/tempering of vibrating-reeds relay (0.5-2.0 ms) is approximately three times less than electromagnetic ones (2.0-5.0 ms). Limit of age (wear resistance) with very small loads ($2 \cdot 10^8 - 2 \cdot 10^9$ commutations) by one to two orders r is more the maximum service of electromagnetic relays ($1 \cdot 10^6 - 5 \cdot 10^7$ commutations).

The symmetrical magneto controlled contacts with circuit closing contact have very simple construction, suitable for mass production in the fully automated production.

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Shortcomings of vibrating-reeds relay they are: the low value of commuted current, the insufficient overload capacity of contacts (in the value of commuted current), of the fragments of contacts during function (by duration 0.3-1.0 ms), the small breakdown voltage among contacts (200-600 V), smaller vibration resistance and impact resistance, the large overall dimensions, the presence of largely only circuit closing contacts (for the realization of the

breaking and stud switches they are utilized supplementary external permanent magnets) and the brittleness of glass tank/balloon.

The great value of the current, switched by miniature and normal vibrating-reeds relay (0.1-1.0a), is approximately five times lower than the current, switched superminiature and miniature electromagnetic relays (0.5-5.0a).

The power, switched by miniature and normal vibrating-reeds relay (4 and 15 W respectively), is 4-7 times less than the power, switched by electromagnetic relays (15 and 100 W). The overall dimensions (space) of vibrating-reeds relay are 2-10 times be greater the overall dimensions of electromagnetic relays. However, the use of the magneto controlled contacts in circuits makes it possible to obtain new technical solutions during a simultaneous decrease in the overall overall dimensions and weights of equipment.

According to fulfilled functions the magneto controlled contacts it is possible to divide not three basic groups: with circuit closing contact, not polarized with stud switch and polarized with stud switch. The magneto controlled

contact with the breaking contact is formed from the magneto controlled contact with the circuit closing contact by means of addition to the latter of external permanent magnet.

Vibrating-reeds relay with stud switch can be also formed by association in one coil of two magneto controlled contacts: with the closing and breaking contact.

By construction the magneto controlled contacts can be divided into seven performances:

a) symmetrical contacts to two springs (reeds) of identical length, derived to opposite sides (Fig. 17-1a, b); b) asymmetric contacts with two springs (reeds) of different length, derived to one side (Fig. 17-1c, d);

c) the nonpolarized asymmetric contacts from two short and one length (movable) by spring, derived to opposite sides (Fig. 17-1e, f);

d) the asymmetric polar contacts with two short and one long spring, derived to opposite sides (Fig. 17-1g);

e) the asymmetric auto/self-polarizing contacts from two long and one short spring, derived to opposite sides (Fig. 17-1h).

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Depending on overall dimensions, the magneto controlled contacts are divided into four typical dimensions: normal (standard), average sizes, miniature and subminiature.

According to pressure and kind of the filling gas, the magneto controlled contacts are divided into gas-filled with the normal pressure of gas (nitrogen with the impurity/admixture of 10o/o helium or hydrogen), gas-filled with the elevated pressure of gas (hydrogen by the pressure of 4-5 at) for the commutation of currents 2-3a and of voltages to 400-500 v and vacuum for the commutation of currents 3-4a and of voltages to 5000 v.

According to the state of working contact surface, the magneto controlled contacts are divided into μ with dry contacts and μ with the contacts, moistened by mercury.

The magneto controlled contacts received wide acceptance

from 1954 in connection by the rapid development of the radio-electronic and computing equipment, required of a considerable increase in the reliability of contacts, elongation of their service life and increase in the operating speed.

Vibrating-reeds relay are applied in different radio-electronic equipment/devices, systems of control, equipment for communication/connection, measuring devices, the systems of reception/procedure and processing, computers, the coaxial switches, which move rapidly coordinate connectors, also, in many other devices.

The most widely used type - the symmetrical magneto controlled contact with circuit closing contact (Fig. 17-1a) consists of two flattened on end/leads wires in the form of flat springs (reeds), prepared from iron fusion with nickel (52o/o), sealed in in the end-type walls of the glass tank/balloon of cylindrical form. Springs are arrange/located coaxially (in parallel planes) and their internal end/leads (contacts) overlap each other approximately by 0.9-1.2 mm.

The internal end/leads of the springs, which perform

the role of contacts, are covered with gold by thermal diffusion, by rhodium or silver galvanically (thickness of the layer of the coating approximately with 6-10 μ).

The outside diameter of the glass tank/balloon of the magneto controlled contact of normal (standard) size/dimensions (Fig. 17-1a) is equal approximately to 5.3 mm, its length about 52.4 mm, overall length together with outputs (conclusion/derivations) - about 82 mm.

The tentative size/dimensions of the internal parts of the springs (reeds) of the magnetc controlled contact are equal to: 0.5 x 2.8 x 18 mm (0.3 x 1.8 x 20 mm). Air gap between contacts oscillates within limits from 0.15 to 0.3 mm. Pressure in the locked contact is within the limits from 10 to 25 g.

Tank/balloon is filled by dry nitrogen with small impurity/admixture of helium or hydrogen at the pressure, close to normal atmospheric.

The weight of the normal magneto controlled contact is equal to 2.0-2.5 g.

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The miniature magneto controlled contact (Fig. 17-1b) has glass tank/balloon as diameter of approximately 3.2 mm and as length 19-21 mm (with conclusion/derivations of approximately 38 mm). The tentative size/dimensions of springs are equal to 0.22 x 1.3 x 0.7 mm. Air-gap clearance between contacts is within the limits from 0.05 to 0.11 mm, the overlap of springs is equal to 0.4-0.6 mm. Weight of contact of approximately 0.3 g.

Vibrating-reed relay consists of the coil (solenoid) within which are located one or several magneto controlled contacts.

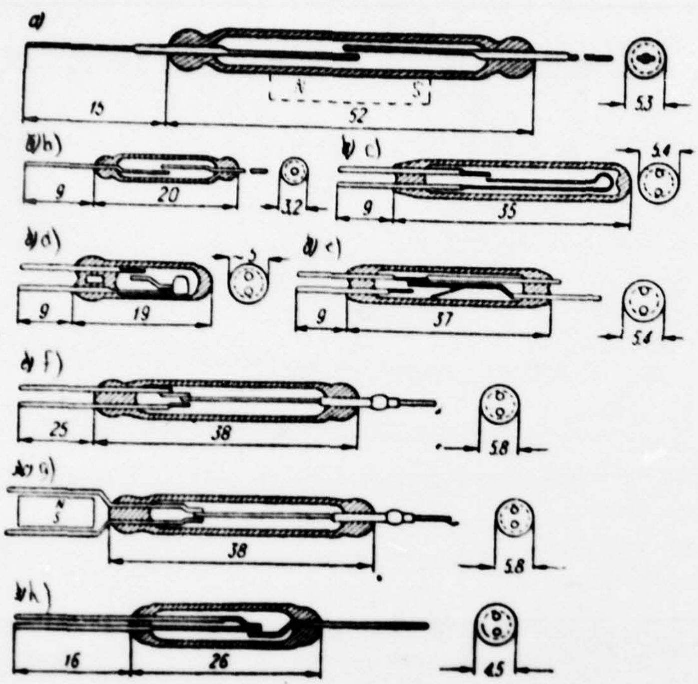

Fig. 17-1. Outlines of magneto controlled contacts; symmetrical with circuit closing contacts, derived to opposite sides: a) are normal; b) miniature; asymmetric with circuit closing contacts, derived to one side; c) average; d) miniature; not polarized with stud switches: e) with return spring; f) without return spring; g) polarized with stud switches; h) auto/self-polarizing with stud switches.

End Section.

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upon the connection/inclusion of the winding of relay, the contact springs (reeds) are magnetized in the field of solenoid and their end/leads (pole) are attract/tightened to each other, closing the circuit of contact system.

Upon the connection/inclusion of the winding of relay, the contact springs return with elastic forces to initial position (they are broken) since the coercive force of Ni-Fe alloy is very small, and magnetic relay circuit from conclusions is extended.

The magneto controlled contact can be led also into action by approach/approximation to it and the distances of the permanent magnet, which is utilized for the creation of mechanical switches and selectors without slipping contacts, working at a high speed (to 5000 r/min), and also many other switchboard/switchgear/switching devices.

If we in parallel to the magneto controlled contact with circuit closing contact fasten the permanent magnet (as this is shown by dotted line in Fig. 17-1a), then contacts will be closed, and we will have the polarized switch with the breaking contact.

For interrupting of these contacts, it is necessary magneto controlled contact together with magnet to place into coil (solenoid) and tax into winding countercurrent, sufficient in value for the demagnetization of the reeds, polarized by magnet. It is necessary to consider that the value of countercurrent must not reach the dual spill current of the breaking contact to avoid magnetic reversal and repeated closure of this contact.

If value M.M.F. of magnet is insufficient for closing of contacts, but it is sufficient for their retention after the connection/inclusion of the current of forward direction, then relay works as remote-control switch from magnetic blocking of armature. During the supplying into the winding of the current pulse of one direction, the contacts are closed, while upon the connection/inclusion of the current pulse of opposite direction, contacts are broken.

Placing into one coil two those who are magneto controlled contacts: one with closing, and another with the breaking contact (polarized by permanent magnet), we obtain polar relay with stud switch.

For a decrease in the interferences (focusing/inductions) in the circuit of contacts with the commutation of currents and stresses of small levels are utilized the magneto controlled contacts whose springs are derived to one side (Fig. 17-1, c, d).

The nonpolarized magneto controlled contact with stud switch (Fig. 17-1, e, f) consists of glass tank/balloon into one of end/leads of which sealed in two short fixed contacts, and in another one movable spring (reed) of iron fusion with nickel.

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If coil current is absent, then the free end/lead of the movable spring by elastic force is pressed to fixed contact from nonmagnetic alloy; upon the connection/inclusion of winding, movable reed blows away from the nonmagnetic and is attract/tightened and to motionless ferromagnetic

(normally disconnected) contact. In the polarized magneto controlled contact (Fig. 17-1, 9) both fixed contacts are manufactured from ferromagnetic alloy and are polarized by external permanent magnet. The polarized magneto controlled contact is characterized by high sensitivity and smaller shaking of contacts.

Figures 17-11 z gives the outline of the auto/self-polarizing magneto controlled contact with stud switch [redacted] [17-17].

In the absence of coil current, average spring is pressed against by upper elastic force. After the connection/inclusion of the winding through both these springs pass magnetic flux, they obtain identical polarity and the end/lead (pole) of average movable spring is repulsed from the upper and is attract/tightened to lower.

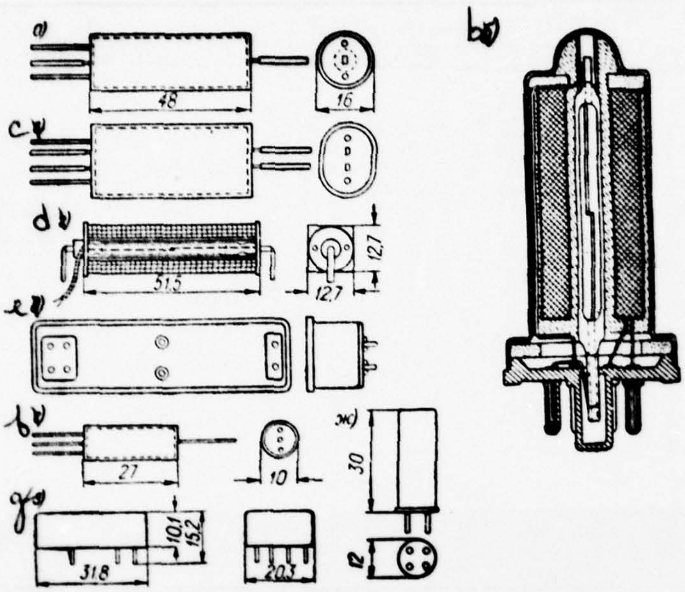

Fig. 17-2. Outlines of vibrating-reeds relay; normal: a - with one circuit closing contact; b) the same with octal base; c) with two circuit closing contacts; d) - with one circuit closing contact without jacket; e) with two circuit closing contacts for printed wiring; miniature: f, g - by one circuit closing contact; h) with two closing and two breaking contact for printed wiring.

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The magnetic flux, passing through the average spring, does not virtually change into the process of switching, since this spring has smaller section and is saturated. Therefore the attracting force, which operates on average spring, as a result of its simultaneous repulsion from upper spring is more than the usual magneto controlled contact with two springs.

Vibrating-reeds relay outside are usually shielded by the jackets (jackets) of cylindrical, oval or rectangular form. For a decrease in the effect of external magnetic fields, these jackets are manufactured from gland. The tank/balloons magneto controlled contacts, which commutate high-frequency circuits and the currents of small levels, are protected by electrostatic shields for a decrease in the interference level in the circuit of contacts.

Vibrating-reeds relay cannot be used for the commutation of very small voltages (several microvolt), since in the reeds, which vary in magnetic during function with frequency of approximately 500 Hz, is induced the mixing stress.

After the closing/shorting of reeds, they continue to oscillate during several milliseconds with high frequency (on

the order of 30 kHz of the miniature relay), moreover noise voltage through 1 ms after closing of contacts decreases approximately to 250 μV, and through 2 ms - to 40 μV.

The oscillations of the annealed reeds attenuate faster as a result of high internal losses, but the strongly annealed reeds can give remanent/residual deformations during vibrations on resonance frequency and impacts.

Figures 17-2 shows the outlines of vibrating-reeds relay of the different types: with one (Fig. 17-2, a, b, d, f, g even two circuit closing contacts (Fig. 7-2, c, e, h). The overall dimensions of vibrating-reeds relay depend on the number of switches and diameter of coil.

Normal relay.

Normal vibrating-reeds relay with one magneto controlled contact have diameter approximately from 12 to 21 mm and length from 48 to 83 mm without conclusions. The space of these relays (without conclusions) is within the limits from

5 to 19 cm^3 and weight from 16 to 40 d.

Vibrating-reeds relay with circuit closing contact can be operated at ambient temperatures from -60 to +85 and +125°C, with vibrations with acceleration 10-20 g in the range of frequencies from 10 to 450-750 (1000) Hz and impacts with acceleration 20-50 g. (Vibration resistance of the magneto controlled contacts, given in Fig. by 17-1, c, ~~g~~ e in the range of frequencies from 10 to 1000 Hz are equal to 3 g).

The resonance frequency of the springs (reeds) of the normal magneto controlled contacts of different types oscillates within limits from 450 to 1000 Hz.

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The ampere-turns of the function of the different types of vibrating-reeds relay with one by circuit closing contact is within limits from 50 to ~~100~~ 110 (130) ampere-turns (on the average 85 ± 10 ampere-turns), the ampere-turns of release/tempering oscillate from 20 to 60 ampere-turns (average value 30 ± 5 ampere-turns).

The ampere-turns of failure are accepted as usually equal not more than 80o/o ampere-turns of actuation the ampere-turns of retention are not less than 55o/o ampere-turns of function.

The resetting ratio of vibrating-reeds relay is within the limits from 0.25 to 0.5 (0.7).

The power of the function of vibrating-reeds relay with one circuit closing contact depends on the size/dimensions of coil (winding) and oscillates within limits from 0.05 to 0.20 W. The windings of relay are prepared to the nominal stresses: 6, 12, 24 (26.5), 48 and 60 (120) c. Greatest power capacity in the winding 1.0-2.0 W.

The nominal constant value current, switched by the contacts of vibrating-reeds relay of different types, is equal to 1.0A, the great operating stress of contacts 115-250 V.

The power, switched by the contacts of vibrating-reeds relay, with resistive load does not usually exceed 15 W. With the commutation of the currents, which give rise to erosion, working contact surface is abraded and is

sputtered. The products of abrasion and atomization/pulverization settle on working contact surfaces in the form of small movable ferromagnetic particles. These particles freely are moved on working contact surface and with accumulation periodically short circuit contacts in the process of commutation, causing the chance failures (single noninterruptings of contacts).

Erosion of contacts has the formulas of needles and outgrowths which gradually increase in height/altitude and they lead in the course of time to the stable shorting (closing/shorting) of contacts. With the excess of the nominal (greatest) value of commuted current two or three times, the contacts are welded on after the small number of commutations.

The service life of the contacts of normal vibrating-reeds relay to the first short duration failure with the commutation of very low currents comprises from $1 \cdot 10^8$ before $2 \cdot 10^9$ functions and with the commutation of nominal load 15 W - from $6 \cdot 10^6$ before $2 \cdot 10^7$ functions. Tentative the curves of the dependences of the service life of vibrating-reeds relay on the amount of commutated power are constructed by author in Fig. 17-3. The service life

normal vibrating-reeds relay varies within the limits, limited by curves 1 and 2.

For a comparison Fig. 17-3 gives the curves of the most probable service life of a miniature electromagnetic relay of the type RES9 (curved 5) and the minimum service life of a subminiature relay of the type RES10 (curved 6). From these curves it follows that the service life normal vibrating-reeds relay is more than electromagnetic with commutation light loads (less than 10-20 W).

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The resistor/resistance of the magnetc controlled contacts oscillates within limits from 0.03 to 0.1 (0.2) ohm; with the wear of contacts, their great resistor/resistance can increase to 0.5-2.0 ohm. The time delay with nominal stress on winding is equal to 1-2 ms, including duration fragment 0.3-1.0 ms. Releasing time is less than 0.5 ms.

Figures 17-4 gives the curves of the dependences of triggering time and release/tempering of vibrating-reed relay cn the amount of power input.

The frequency of switchings of vibrating-reeds relay is more than 200 Hz. The time delay with stud switch is equal to 2-4 ms (including duration fragment 1-2 ms). The time of the flight/passage of contact is equal to 0.5-1.0 ms, including duration fragment. The releasing time of relay is less than 0.8 ms.

The capacitance/capacity between the dead contacts of the magneto controlled contact with circuit closing contact in the absence of screen is within the limits from 0.5 to 1.0 pF.

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)

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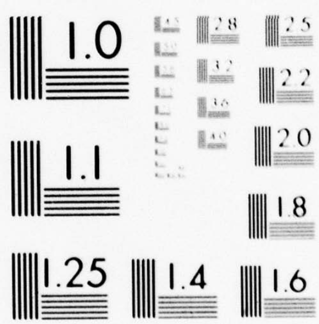
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
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1.4
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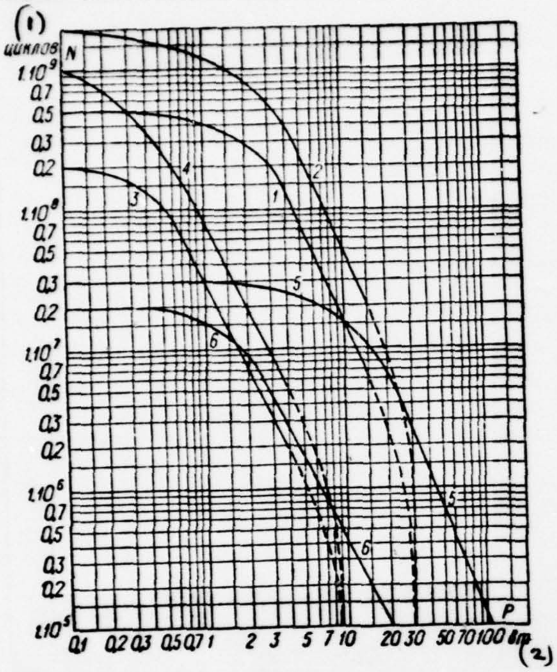

Fig. 17-3. Curved of dependences of service life vibrating-reeds relay with circuit closing contacts on amount of switched power: 1, 2 - normal vibrating-reeds relay ($I_M \leq 1$ a); 3, 4 - miniature relays ($I_M \leq 0{,}125$ a); 5 - electromagnetic relays of type RES9 (most probable value); 6 - electromagnetic relays of type RES10 (minimum value).

Key: (1). cycles. (2). W.

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The insulation resistance of the magneto controlled contacts under normal conditions is equal from 500 to 10^5 MΩ, but at relative humidity 98o/o and temperature +20 °C - is more than 100 Mom.

The testing voltage of insulation of the magneto controlled contacts is found usually within limits from 350 to 600 (1000) V eff. The level of emf of focusing/inductions and noises, introduced into the switched circuit, is approximately 300 μV. For a decrease in the contact resistance to the high-frequency currents (from 10 to MHz) of spring (reeds) and the conclusions of the high-frequency magneto controlled contacts are copper-plated. The internal end/leads of the springs (contacts) are covered with gold. The magneto controlled contacts are utilized in the high speed coaxial switches for the commutation of the circuits of high-frequency telephone equipment.

The magneto controlled contact can be also sealed in inside coaxial cable. In this case the field coil has larger diameter and is put on to cable outside above the contact.

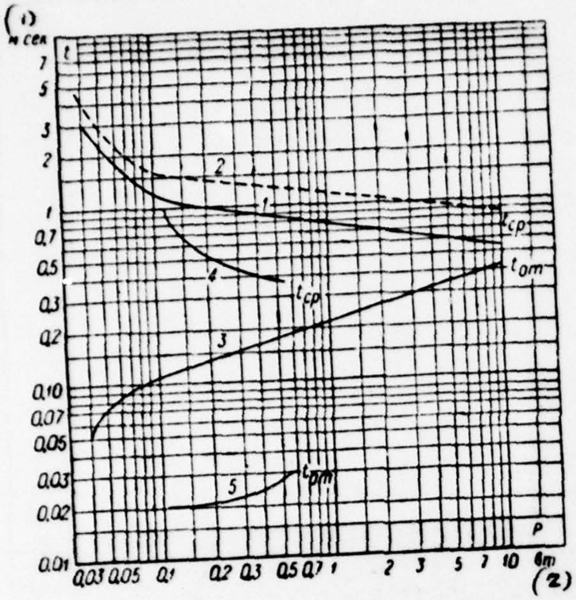

Fig. 17-4. Curved of triggering time and release/tempering of vibrating-reeds relay; normal relays: 1 - triggering time without taking into account the shaking of contacts; 2 - the same taking into account shaking of contacts; 3 - releasing time; miniature Rayleigh 4 - triggering time; 5 - releasing time.

Key: (1). ms. (2). W.

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Vacuum vibrating-reeds relay are utilized for the

commutation of currents to 3 A and stresses to 1500 and 5000 V of the direct current with commutated power, equal to 25-50 W. The ampere-turns of function are within the limits from 60 to 100 ampere-turns. Triggering time is equal to 2-3 ms (including duration the fragment of contacts).

The testing voltages of the contacts of these relays are respectively equal tc 2000 and 10000 V. Contact resistance is equal from 0.025 to 0.08 ohm. Capacitance/capacity between the contacts 0.8 pF.

The magneto controlled contacts with the contacts, moistened by mercury, can commuted currents to 3A and stresses of up to 400V direct current at the switched power to 50 W. The service life of contacts with resistive load 50 W is equal to $1\cdot10^7-1\cdot10^8$ functions. However, these contacts cannot be operated at the temperatures below -38.9°C and under conditions of vibration.

Miniature relay.

Miniature vibrating-reeds relay (Fig. 17-2, d, g, h with one circuit closing contact have a diameter approximately from 9 to 19 mm and length from 24 to 35 mm (without conclusions). The space of these relays is within the limits from 1.8 to 9 cm^3 and weight from 5 to 20g. The specific gravity/weight of vibrating-reeds relay oscillates approximately from 2.8 to 2.0 g/cm^3 instead of 2.8-4.1(5.3) g/cm^3 of electromagnetic relay.

Miniature relays can be operated at ambient temperature from -60 to +85, +125°C, vibrations with acceleration from 15 to 35 g in the range of the frequencies from 10 to 2000 Hz and with impacts with acceleration of 30-75 g. The resonance frequency of the reeds it is within the limites from 2500 to 3500 Hz.

Miniature vibrating-reeds relay have ampere-turns of function from 20 to 50 ampere-turns and the ampere-turns of release/tempering from 8 to 30 ampere-turns. Resetting ratio oscillates from 0.2 to 0.6(0.9). The power of the function of relay with one circuit closing contact is from 0.02 to 0.15 W. The windings of relay are manufactured to the nominal stresses: 6.12, 26, 48 and 125V. The greatest power capacity in the winding of relay is equal to 0.5-1.0 W. Nominal constant value current, switched by contacts miniature relays, 0.1-0.125 (0.25)A, the great operating

stress of contacts 115-250 V. The power, switched by the contacts of relay with resistive load, does not exceed 3-4 W or 10-12 volt-amperes.

The service life miniature vibrating-reeds relay varies within the limits, limited by curves 3 and 4 in Fig. 17-3. From these curves it follows that with the commutation of nominal load 4 W the service life is within the limits from $2 \cdot 10^{6}$ to $5 \cdot 10^{6}$ functions, and with the commutation of very low currents - from $2 \cdot 10^{8}$ to $1 \cdot 10^{9}$ functions. The service life miniature vibrating-reeds relay is more than electromagnetic with commutation light loads (less than 2-5 W).

Contact resistance - from 0.05 to 0.2 ohm; in the process of wear their great resistor/resistance can increase to 2 ohm.

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Time delay with nominal stress on winding of approximately 0.5-1 ms, including duration fragment 0.3 ms, releasing time less than 0.1 ms. The frequency of switchings of miniature relays is more than 400 Hz. The

capacitance/capacity between extended contacts in the absence of screen is equal to 0.2-0.5 pF. Insulation resistance is from 10^2 to 10^4 MΩ. The testing voltage of insulation is equal from 200 to 500 V eff.

Switching system of the type "ferride".

High speed changing over device of the type "ferride" (Fig. 17-5) consists of one either several magneto controlled contacts, one or several alternating/variable magnets (rods from the cobalt or cobalt-zinc ferrite, which has coercive force of approximately 30 e and very high resistivity) and magnetizing coil [17-10].

For the function of the contacts of "ferride" it is sufficient so that the duration of operating pulses in winding would be not less than 10 μs (time, necessary for the magnetic reversal of magnet from ferrite). The magneto controlled contacts of "ferride" will actuate/operate considerably later (approximately through 0.5-0.8 ms after cycling into winding and the magnetic reversal of ferrite) and will remain in the pullled position.

For the return of the contacts of "ferride" to initial position it is necessary to feed to winding the current pulse of opposite direction with smaller amplitude by the duration of more than 10 μs.

"Ferride" has small overall dimensions and high speed of response, it can in a number of cases replace the semiconductor changing over devices and equipment/devices.

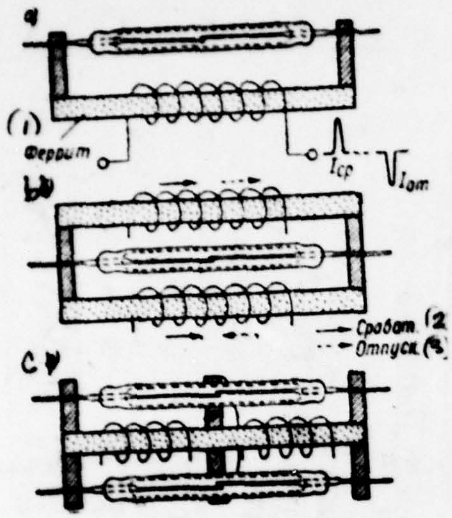

Fig. 17-5. Moving rapidly switching systems of type "ferride": a) elementary circuit of "ferride"; b) parallel "ferride"; c) consecutive "ferride".

Key: (1). Ferrite. (2). Triggering. (3). Release.

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From all that has been previously stated, it follows that vibrating-reeds relay are very promising, are characterized by high reliability, small and stable in the value contact resistance, very larger service life at the light loads of contacts, smaller triggering time and

release/temperings and simpler construction, than electromagnetic relays. However, the power, switched by vibrating-reeds relay, is less, their overall dimensions are be greater and vibration resistance is less than in electromagnetic relay. Therefore gas-filled vibrating-reeds relay in many instances cannot replace miniature/small and miniature airtight electromagnetic relays.

17-2. Relays with mercury contacts.

For a reliable commutation with the increased velocity of comparatively large power of direct current without the vibrations (fragment) of contacts, with very large service life (it is more than billion functions), are applied gas-filled relays with the platinum contacts whose surface is constantly wet by mercury.

Fig. 17-6 shows in cut/section the outline of relay with mercury contacts of series HG of firm "Ts. P. Klea and of Ko" (USA), mounted in the housing of metallic electron tube with the octal base [redacted]. [17-2]. Relay consists of coil (solenoid), within which is arrange/located glass

tank/balloon with the stud switch, in lower part of which a filled small quantity of mercury.

In the lower part of the glass tank/balloon, is sealed in the stem from ni-span alloys to which is welded the lower pole piece and the foundation with flat spring and armature from Permalloy, submerged partially into mercury.

Along armature are welded two parallel platinum wires whose the upper part of outside armature is locked in the form of the letter of "t" and is the slide contact of relay.

Mercury rises to contacts on the capillary, formed between these two parallel platinum wires.

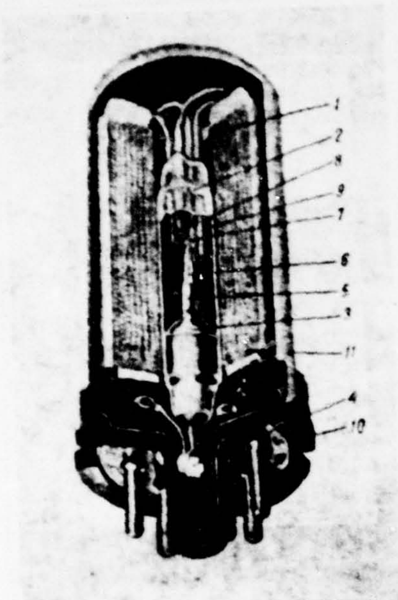

Fig. 17-6. Relays with mercury contacts of series HG. 1 - coil; 2 - glass tank/balloon; 3 - mercury; 4 - stem; 5 - lower pole piece; 6 - armature; 7 - slide contact of armature; 8 - motionless breaking contacts (short); 9 - strip with motionless circuit closing contacts (long); 10 - octal base; 11 - housing (jacket).

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Mercury rises to contacts on the capillary, formed

between these two parallel platinum wires.

In upper part of the glass tank/balloon, it is sealed in four iron-nickel rods to end/leads of which, turned to armature, are welded four motionless platinum contacts.

In the absence of coil current, flat spring of armature presses the horizontal part of the movable T-shaped contact to two fixed contacts, arrange/located on two short rods (to the left). The patterns of the joints of relay are given in Fig. 17-7.

Upon the connection/inclusion of the winding of relay, the free end/lead of the armature is attract/tightened to the end/leads of two long rods (poles) from ni-span alloys, arrange/located to the right to which somewhat above are welded two motionless (normally extended) of contact.

During the function of relay, the horizontal part of slide contact blows away from the right pair of contacts and closes by itself the left pair of fixed contacts.

The thin layer of mercury, which wets platinum contacts, excludes the possibility of the short-term

disruption of contacts with the rebound of armature after the impact against the pole piece and shields contact surface from erosion, wear, contamination, sticking and welding.

During interrupting of the contacts between them, is extracted the bridge from mercury which is disruptted at a very high speed, at two points free/releasing the droplet of mercury.

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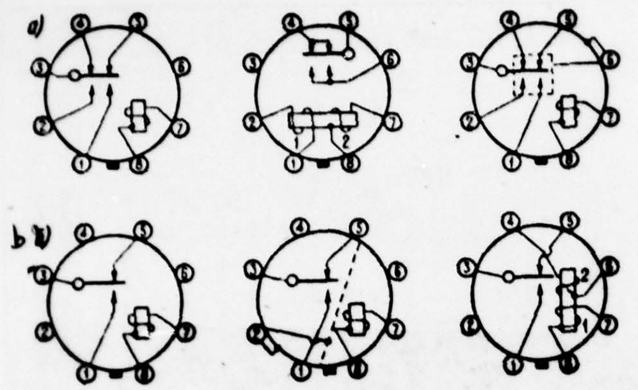

Fig. 17-7. Diagrams of conclusions of relay with mercury contacts: a) series HG, b) series HGS.

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High rate of the disruption of bridge from mercury between contacts (acceleration about 1500g) excludes the possibility of the occurrence of vibration and formation of the arc between contacts and provides the very large service life of relay at the comparatively large switched power. The relay of series HG can switch direct current to 5A and stress of up to 500V at breaking capacity to 250 W.

The service life of relay with the load of contacts in 250 W is more than 10^9 functions (commutations).

The glass tank/balloon of relay is filled by hydrogen under the pressure of 15-17 at, which considerably increases the voltage of breakdown and eliminates the oxidation of mercury.

Relay maintain/withstands ceiling voltages between contacts of up to 8500 V.

The contacts of relay must be shielded from overvoltages by the spark-extinguishing duct RC whose parameters can be determined from the following formulas:

$$C = 0{,}1 \cdot I^2 \overset{(1)}{\text{мкф}} \overset{(2)}{\text{и}} R = \frac{U}{10 \cdot I^k} \Omega.$$

Key: (1). µF. (2). and.

where I is a current in a, U - the stress in V and k = 1 + 50/U.

The minimum values C = 0.001 µF and R = 0.5 ohm.

Pressure in the breaking contact of approximately 1 g.

Contact resistance from 0.025 to 0.06 ohm. In the process of the operation of relay, the contact resistance changes not more than on 1-2 mΩ.

Duration of the closing/shorting of mercury contacts in the atmosphere of hydrogen at the pressure of 15-17 at of order 10^{-10} s (0.5-0.8 ns) instead of 1-10 ns of the metallic contacts, not moistened by mercury. Interrupting time (cutoff) of the circuit of the mercury contacts of order 10^{-9} s. Inductance of the winding of relay L = $1.2 \cdot 10^{-8} \cdot w^2$. Time delay from 3 to 5.2 ms with nominal stress on winding of approximately 3 ms; releasing time 3.2 ± 0.6 ms. The time of closing (shorting) of contacts is less than 1 ms.

Stability of triggering time of the separate copy of relay of approximately 0.1 ms. Frequency of switchings to 100 Hz. Capacitance/capacity between the contacts 3-8 pF.

Relays are manufactured with one or two windings to operating stress from 1 of up to 200V, winding impedance from 2 to 25000 ohm.

The ampere-turns of the function of relay of the type

HG are less than 124; the ampere-turns of retention are more than 147 and the ampere-turns of release/tempering are not less than 84.

The power of the function of relay is not more than 0.25 W. The greatest power capacity in winding at ambient temperature of +38°C is equal to 2 W, greatest temperature is determined by the softening temperature of sealing compound of winding 107°C.

Relay is intended for operation under stationary conditions at the temperature of surrounding air not below - 38.9°C (freezing point of mercury).

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The normal operating position of relay the vertical, standard deviation from vertical line is not more than 30°. Relay maintain/withstands vibration test in the range of frequencies from 10 to 500 Hz during acceleration 10g and impact strength during acceleration 30 g.

Overall dimensions of the relay of series HG: diameter 28.1 mm length 67 (81.2) mm. Weight 113g.

The relays of types HG 2A, HG 3A and HG 4A are characterized by the high diameters of the coils within which are arrange/located respectively two, three or of four mercury switches.

Are manufactured also mercury switches in the form of parallelepiped, intended for printed wiring.

Polarized mercury switch of series HGP is characterized by from the relay of series HG the presence of two permanent magnets, arrange/located at upper leading-out rods (poles), which have identical length.

Ampere-turns and the power of the function of relay with one-sided adjustment respectively 70 ampere-turns and 35 mW, with two-position adjustment ±35.1 (40.7) ampere-turns and ±9 (12) mW.

Overall dimensions of the relay of series HGP: diameter 28.1 mm and length 79 (93) mm. Weight is not more 130g.

Polarized mercury switch of series HGS is characterized

by greater sensitivity and smaller triggering time, than the relay of series HGP [redacted] [1-26, 17-9, 17-10].

The relay of series HGS (Fig. 17-8) has another construction of armature and poles and considerably smaller length of tank/balloon. The armature of relay is flat spring with two contacts on end/lead. In the upper part of the tank/balloon, are sealed in two rods from ni-span alloys, that conclude with inside flat/plane pole pieces with the welded-on by them contacts. On top above the coil perpendicular to leading-out rods are fastened two permanent magnets.

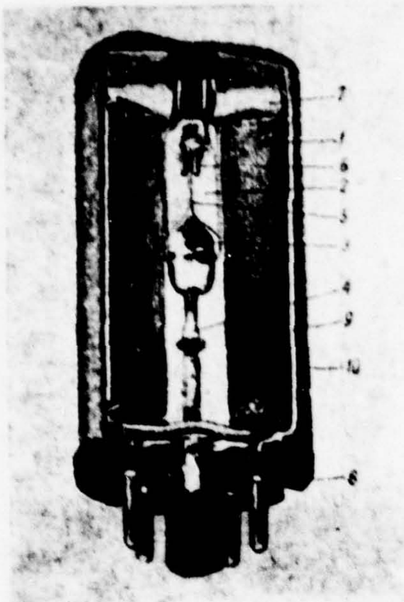

Fig. 17-8. Relays with mercury contacts of series HGS. 1 - coil; 2 - glass tank/balloon; 3 - mercury; 4 - stem; 5 - armature with fixed contact; 6 - pole with fixed contacts; 7 - permanent magnets; 8 - octal base; 9 - magnetic circuit; 10 - housing (jacket).

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The glass tank/balloon of the relay of series HGS and HGSS has approximately to 50o/o smaller length, than a

tank/balloon of relay of series HG and HGP.

The relay of series HGS is manufactured from unilateral or two-position regulation; ampere-turns and the power of the function of relay with respect 27.3 ampere-turns and to 5 mW or ±15.3 ampere-turns and ±2 mW. Power, dispersed by winding, 2 W.

Time delay from 1.1 to 1.8 ms (with 200 mV — t_c = 1.4 ± 0.4 ms), releasing time 1.4 ± 0.5 ms. The time of the overlap of contacts is not more than 0.5 ms. Frequency of commutations to 200-350 Hz.

The load of contacts to 2A great stress 500V; the switched power is not more than 100 W. Service life is more than 10^9 functions. Winding impedance from 2.8 to 14000 ohm. The relays of series HGP and HGS are manufactured also with the contacts of form C (closing/shorting after interrupting n. z. of contacts), triggering time of these relays is somewhat more than relay with the contacts of form D (closing/shorting before interrupting).

Overall dimensions of the relay of series HGS: diameter

31.4 mm length 67 (84) mm. Everything 140g.

The relays of series HGSS are characterized by from the relay of series HGS the smaller length of coil and the respectively larger power of function -12 and ±4 mW. Power, scattered by winding, 1.5 W.

Overall dimensions of the relay of series HGSS: diameter 31.4 mm and length 47.6 (62.8) mm. Weight is not more 85g.

17-3. Tuned-reeds relay.

One Of the simplest and reliable methods of remote control the removed objects is the method of the frequency separation of signals, which makes it possible to transmit along one channel (wire) the large number of command/crews.

For the premise/impulse of frequency signals, usually are applied the frequencies of tonal range.

The receiver of frequency signals consists of the

filtering and actuating elements which can be made either separately in the form of filter and connected at its output usual relay or together in one tuned-reed relay.

The best filtering properties with the smallest overall dimensions in the range of tone frequencies possess the electromechanical filtering systems, constructed on the application/use of the rod transverse-oscillating vibrators. In these systems the electrical energy is converted into mechanical vibrational energy of the rods, inclined for one specific frequency. Mechanical vibrational energy of rods in tuned-reeds relay is utilized directly for the closing/shorting of performing contacts, and in filters again it is converted into electrical energy.

Receiver circuits of frequency signal with electromechanical filter and with tuned-reed relay are given in Fig. 17-9.

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Tuned-reeds relay are intended for work at the fixed/recorded frequencies usually in the range from 100 to 1500 Hz, since relays for lower frequencies (from 15 to

100 Hz) have comparatively large overall dimensions.

The schematic diagram of tuned-reed relay with the single transverse-oscillating rod vibrators (reeds) is shown in Fig. 17-10b.

Tuned-reed relay consists of electromagnet with core of sheet iron or Permalloy even one or several (3, 4, 6 or 12) side-by-side rod vibrators (reeds) of different length, attached by one end/lead on the framework of electromagnet.

On vibrators are fastened the slide contacts of relay, the fixed contacts are soldered to the end/leads of the adjusting screws which are covered into rigid contact holders arrange/located on insulating board.

For a decrease double in the frequency of the forcing oscillations, attracting force of vibrator and increase in the sensitivity consecutively into magnetic relay circuit is placed the constant polarizing magnet.

The magnetic flux of relay is closed through the vibrator and the working air gap between vibrator and pole of electromagnet.

The natural vibration frequency of vibrator (resonance frequency) according to formula (12-3) depends on its length, thickness and the modulus of elasticity of material.

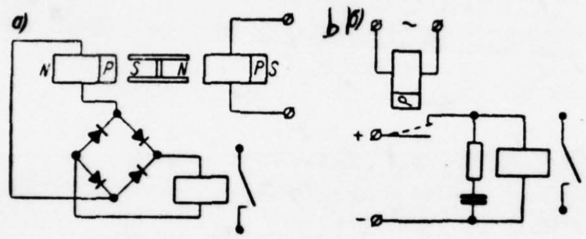

Fig. 17-9. Receiver circuits of frequency signal; a - c by electromechanical filter; b - c by tuned-reed relay.

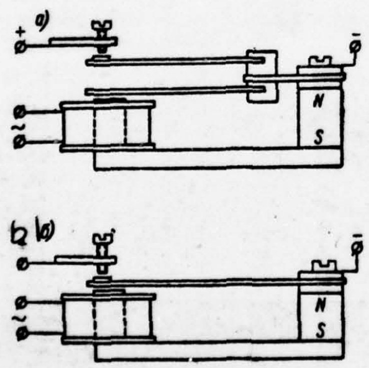

Fig. 17-10. Schematic diagrams of tuned-reeds relay: a - c

by two connected vibrators; b - c by single vibrator.

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Vibrators usually are manufactured from steel. In certain cases for providing the high stability of resonance frequency, the vibrators are manufactured from the Elinvar, which is characterized by the constancy of the modulus of elasticity during a change in the temperature from -50 to +100°C.

The gap between the contacts of relay is very small (0.02 mm); therefore the load of contacts must not exceed 10-100 mA. For the protection of contacts, it is necessary to apply spark-extinguishing duct (RC).

The contacts of tuned-reed relay during function jar with resonance frequency; therefore for providing the stable contact in performing circuit, usually is applied the repeating relay without amplifier or with transistor amplifier. Power, consumed by tuned-reeds relay, from 1 to 20 (100) mW. The actuation voltage is from 0.5 to 15V.

The bandwidth of tuned-reeds relay depending on their construction for a frequency band from 250 to 500 Hz is within the limits from 6 to 20 Hz (from 2 to 8o/o).

On the lower limit of the frequency band of channels, are spread on 20 Hz, at frequencies higher 175 Hz - on 40 Hz.

relay with single vibrators have a selectivity characteristic, which considerably differs in its form from the rectangular; therefore the bandwidth of the function depends on signal level.

Relays with two connected vibrators, developed A. Ya. Melnichuk (Fig. 17-10a), have a selectivity characteristic, close to rectangular [1. 17-13].

The selectivity characteristic of this relay is given in Fig. 17-11.

Such relays can be manufactured for frequencies from 150 to 1000 Hz. The band of the frequencies of the function in this case can be regulated within limits from 4 to 15 Hz (from 1 to 4o/o) depending cn coupling

coefficient between vibrators. The minimum power of function is approximately 10 mVA.

Triggering time of tuned-reeds relay 50-100 ms, while releasing time 90-200 ms.

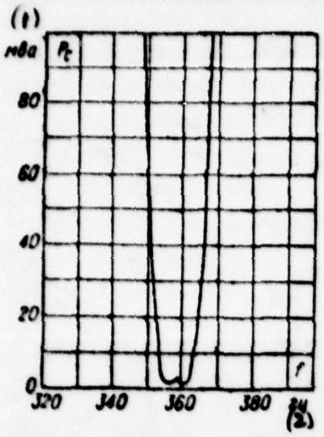

Fig. 17-11. Selectivity characteristic of relay with two connected vibrators.

Key: (1). mVA. (2). Hz.

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ELECTRICAL CONTACTS.

18-1. General information.

The electrical contacts, used in electrical apparatuses and instruments, are distinguished between themselves by the operating principle and construction and accordingly can be divided to three basic groups: the motionless, disruptive and sliding contacts.

The greatest group they are the sparking contacts, used in the electrical relays, the contactors, the switches, the switches and other electrical apparatuses. In the locked, motionless state the disruptive and sliding contacts, obviously, must satisfy the requirements, presented to fixed contacts.

The character of the wear of sparking contacts depends substantially on the value of the switched power, current and stress. In the amount of the switched power, the

sparking contacts are divided into low-power (weak-current), moderately loaded and highly stressed (high-current).

To electrical sparking contacts are presented the following fundamental requirements: very low and constant in value contact resistance, small erosion and corrosion, large wear resistance, a small tendency toward needle formation and sticking, high electro- and thermal conductivity, the high melting point, the absence of distortions at work (absence of the jarring of contacts), large reliability and large service life.

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18-2. Contact resistance.

The contacts of relay usually have working surface in the form of hemisphere, semicylinder or plane. In the locked state the contacts are pressed against each other with certain effort/force F_{K}, which it is called contact effort/force or contact pressure. As thoroughly not had been polished contact surfaces, as a result of the presence of

inequalities (microroughness) the real contact of the contacting points will always occur only at one either several points will always occur only in one or several projecting very low surfaces ("points" or area/sites). Current passes only through the small true contact surfaces in which is created metallic or quasi-metallic contact.

Quasi-metallic contact is realized through monomolecular surface films because of tunnel effect and the formation of the which penetrate film metallic bridges by a diameter of approximately 0.3 μ. The remaining large part of the contact surface is usually covered with the badly/poorly conducting or insulating films of oxides, nitrides, carbides, sulfides and the like or completely does not come into contact with the second contact surface. Therefore parallel flow lines in the metal of contacts are bent and brace themselves to the points with high conductivity, at which the current density can reach the very high values (10^7 A/mm²).

The contraction of flow lines to contact area/sites causes supplementary increase in the contact resistance, which is conventionally designated as the resistor/resistance of contraction R_c.

The resistor/resistance of the contraction of contact at one contact "point" can be expressed by following formula [redacted] [18-17]:

$$R_c = \frac{\rho}{2}\left(\frac{1}{a} - \frac{1}{r_1}\right). \qquad (18\text{-}1)$$

where ρ - a specific strength of materials of contacts in Ω•cm, a - a radius of the area of contact "point" in cm (or an equivalent radius of several contact "points") and r_1 - a radius of the cylindrical body of contact in cm.

Usually value r_1 is considerably greater than a; therefore the effect of the second term in brackets can be disregarded. In this case [redacted]

$$R_c = \frac{\rho}{2a} \qquad (18\text{-}1a)$$

If both contacts of one contact pair are made from different materials, then

$$R_c = \frac{\rho_1 + \rho_2}{4a}. \qquad (18\text{-}1б)$$

At neutral contact pressures F_k (about 10 g) at contact "points" occurs the warping of material, and therefore specific pressure can be considered the approximately equal to the hardness of material H:

$$\frac{F_к}{\pi a^2} = H, \text{ откуда } a = \sqrt{\frac{F_к}{\pi H}}.$$

Key: (1). whence.

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According to this formula, at a pressure in 15 g for the silver contacts a = 8.5 μ;

substituting in equation (18-1a) instead of a its value, we obtain:

$$R_к = 0{,}886\rho \sqrt{\frac{H}{F_к}}. \quad (18\text{-}2)$$

If pressure in contacts $F_к$ is expressed in grams, H in kg/cm² and ρ - in Ω•cm, then

$$R_к = 280\rho \sqrt{\frac{H}{F_к}}. \quad (18\text{-}2a)$$

At low contact pressures (about 1 g) at contact "points" occurs the elastic deformation. In this case, according to hertz formula, a radius of the area of contact "point"

$$a = 0{,}86 \sqrt[3]{\frac{F_к r}{E}}.$$

where r is a radius of the sphere of contact and

E the modulus of elasticity of material.

Substituting in equation (18-1a), we obtain:

$$R_к = \frac{\rho}{1{,}72\sqrt[3]{\frac{F_к}{E} r}}. \quad (18\text{-}3)$$

Under actual conditions the contact resistance consists of the sum of the resistor/resistances of contraction and film:

$$R_к = R_c + R_п.$$

At the sufficiently large contact pressures of film, they are disruptted as a result of the plastic deformation of material at contact "points" and $R_к$ is determined in by basic value R_c. On the contrary, at low contact pressures the resistor/resistance of film plays the significant role.

On the working any contact surface in air, usually very rapidly are formed the surface films of chemical compounds - oxides, sulfides, chlorides, carbides, hydrides and of so forth, that increase the total resistance of contacts. These films are invisible, it have thickness less than 100 Å (0.01 μ). Surface films can be organic and

inorganic origin, they can be the products of polymerization or decay. Furthermore, contact surfaces can be covered with coatings or dust of different composition, with nonconducting particles and filaments.

The formation of surface films occurs as a result of the adsorption of the molecules of gas by metallic contact surface.

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Adsorbed molecules through certain time dissociate during simultaneous electron exchange with the adsorbing medium (chemical adsorption). Metal ions are free/released from space lattice and react (chemical reaction) with the chemically adions of gas. In the formed thus surface film roam both the ions of metals and the electrons, which were freed from space lattice, and the electrically charged atoms of gas, thus far they do not enter into reaction.

With the commutation of current, the processes of filming considerably become complicated as a result of the effect of electrical spark or arc on the surface of metal and resolution of organic vapors.

Filming occurs in very small time interval, thus, for instance, atomically pure surface of tungsten (obtained incandescence at temperature of 2000°C in high vacuum) is cover/coated with the film of molecular thickness in

nitrogen or oxygen at atmospheric pressure approximately after 10^{-8} s, and the thickening (growth) of film slows down rapidly and ceases in several milliseconds.

Precious metals in air are cover/coated with film approximately with the same speed as tungsten, but an increase in the film continues considerably longer (on gold - several days, on silver - several hours, and on platinum and its alloys with iridium - several seconds).

The resistor/resistance of the film, which covers contacts, can be expressed by the following formula:

$$R_n = \frac{\rho_n \delta}{\pi a^2} = \frac{\sigma}{\pi a^2}, \qquad (18\text{-}4)$$

where ρ_n - specific resistor/resistance of film, δ - its thickness and σ - specific "skin drag", in $\Omega \cdot cm^2$, determined experimentally and more convenient for calculations.

Value R_n calls also the skin drag of contact.

The specific skin drag of film σ for gold and silver equally approximately $5 \cdot 10^{-9}$ ohms·cm².

The magnitude of σ in the case of very thin films ($\delta < 50$ Å) does not depend on temperature, but with thick films ($\delta > 100$ Å), depends on

temperature just as specific resistor/resistance of semiconductors.

According to the structure of film, they can be continuous and porous. Continuous films with thickness up to several hundreds of Angstrom do not in practice affect electrical contact. Such films can exist, also, on noble metals in the form of the adsorptive films of the moisture and other substances.

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Thicker tarnish narrower affect the conductivity of contacts at very small voltage/stresses and low pressures.

The films with thickness more than 5000 Å have considerable effect on electrical contact up to the disturbance/breakdown of its conductivity.

Brittle films are less harmful, than soft, since they easily break down themselves during the collisions of contacts.

Plastic films are indented into the interval/gaps between contacting points, having gradually filled them and bringing finally to the disturbance/breakdown of contact.

If we at very low contact pressure increase voltage/stress on contacts of up to certain value, called the "fritting voltage", then the skin drag of film suddenly disappeared (film seemingly it breaks down). This phenomenon is called "fritting" and thus far does not have complete explaaation.

With the voltage/stress, which exceeds the "fritting voltage", films they break down, and contact is establish/installed within the penetrating films metallic bridges.

Are distinguished two forms of fritting: A - fritting, which occurs with voltages from 0.5 to 1 V, and B - fritting with voltages 0.01-0.2 V between contacts. The strength of field in surface film with fritting reaches 10^{6} V/cm.

In practice fritting is observed at very low pressures in contact, and also with thick badly/poorly conducting surface films. Therefore for reliable closing of contacts,

pressure in contact must be sufficient for the plastic deformation of material at contact points during which the films are disruptted. Furthermore, it is desirable, so that the contacts during closing/shorting would fit themselves, that as in this case film is remove/taken (it strips itself) mechanically.

With light electrical loads soft metals (for example pure/clean silver) in the process of fitting-in can be polished. In such cases it is better to apply more hard alloys. With small fitting-in for gold, the pressure in contact can be less than 1 g, and for silver must be on the order of 10-15 g.

With the content in humid air of sulfuric anhydride (SO_2) or of hydrogen sulfide (H_2S) in relationship/ratio 1:10⁹ on silver is formed the film of silver sulfide (AG_2S), that has high specific resistor/resistance (10^3-10^8 Ω•cm). This concentration of hydrogen sulfide always is in industrial areas. With an increase in hydrogen sulfide concentration to 1:10⁶ (in the presence of sulfur containing types of rubber, effect of the perspiration of hands, etc.) silver turns black.

The palladium and platinum contact surface, working without electrical load, is cover/coated with thin film from polymerization products of organic vapors.

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At the edges of contact area/site, collects dark brown or black powder.

With prolonged idleness on tungsten contacts, which are found in closed plastic housing, is formed the transparent organic film of high resistor/resistance.

The resistor/resistance of such film can reach several megohms, and the fritting voltage 200-300 V.

With very small voltage/stresses frequently is observed a considerable increase in the contact resistance from precious metals (brass, bronze the like). For the elimination of similar phenomena, is applied the flow of auxiliary direct current about the contacts of small value 0.2-10 mA.

The magnitude of contact pressure for a highly sensitive relay is within the limits from 0.3 to 2 g, sensitive relay are from 2 to 10 g, telephone and control relays are from 10 to 30 g and auxiliary relays of automation from 50 to 100 g. For tungsten contacts is required the increased contact pressure normally from 40 to 120 g, and with large loads to 350 g.

Tentative the curves of the dependences of contact resistance of the contacts of the relays, governing the circuits of small power, on the value of contact pressure are given in Fig. 18-1. In this figure by dotted line are shown the upper limits of a possible increase in the contact resistance. It is necessary to note that instead of contact resistance of contacts frequently erroneously is measured the total resistance of contacts and contact springs, which is considerably greater than contact resistance of contacts. Thus, for instance, resistance of the contact spring of relay of the type RPN is equal to 0.0163 ohm, and the resistor/resistance of silver contacts oscillates within limits approximately from 0.0006 to 0.0027 ohm.

Figures 18-2 shows the curves of the dependences of contact resistance on contact pressure for pure/clean palladium contacts.

palladium contacts.

At pressures of less one gram, transient pressure sharply increases. This is explained to the fact that the low pressures are insufficient for the complete destruction of the fine/thin absorbtive nonconducting film, which is formed on contact surface and which decreases the number of contact points.

Thus, for the reliable work of pure/clean palladium contacts pressure must be more than 1-2 gf.

For contact resistance, have great effect also the insignificant traces of metals - iron, coppers, nickel or lead, which remain on contact surface as a result of wire drawing (rolling of tape) and of the riveting of contacts, and also the settling with soldering or victuals of the contacts and other parts relays.

These metals are oxidized are caused in the course of time an increase in the resistor/resistance, short duration failures and the failures of contacts.

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To reveal/detect the traces of these metals is possible only under microscope with an increase 200 times.

Thus, the contact resistance of relay depends on a very large quantity of different physical and chemical processes, which take place on contact surface. Furthermore, on contact surface are deposited dirt particles, dust and wear products of the movable friction parts of the relay. Therefore contact resistance depends on construction, technology of production and materials from which are made by relay the contacts, and also from value and character of the electrical load of contacts, conditions of their operation and composition of surrounding air or gas.

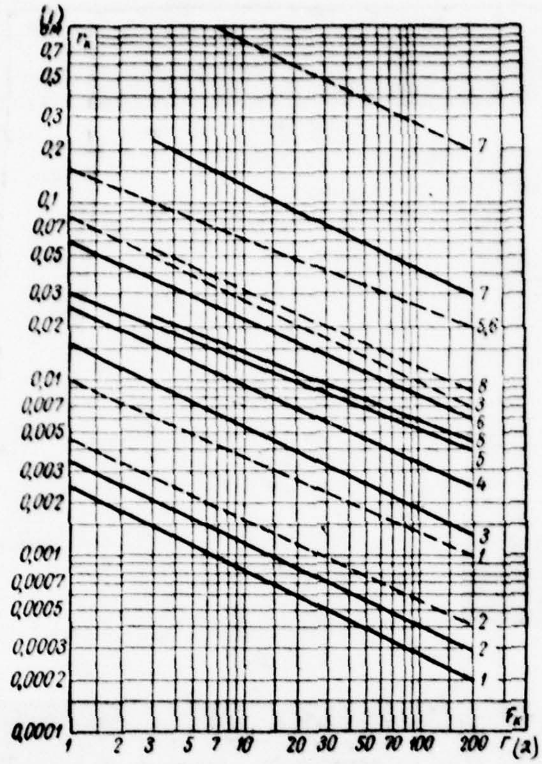

Fig. 18-1. Curved of the dependences of contact resistance of the contacts of relay on the value of contact pressure (d = 2 mm). 1 - silver; 2 - gold; 3 - palladium; 4 - gold-nickel 5o/o; 5 - platinum; 6 - platinum-iridium 10o/o; 7 - tungsten (d = 4 mm) 8 - rhenium.

Key: (1). Ohms. (2). gf.

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Investigations showed that the contact resistance of relay in as-received condition can oscillate within sufficiently large limits, but a considerable increase in it will be observed usually into 1-2o/o of cases.

For example, the contact resistance of the relay of the types RES9 and RES10 with contacts from alloy PlI-10 usually oscillates within limits from 18 to 30-50 mΩ (with current 0.1A), but of 1000 samples approximately in 20 cases it can reach to 0.5-1.5 ohm, and in ~~two-three~~ three-four cases to 2.0-3.0 ohm. Of relay of the type RES9 with silver contacts, the contact resistance usually oscillates from 11 to 25 mΩ, and into 1o/o of cases, it can reach to 0.2-0.6 ohm.

According to the data of foreign firms, with the commutation of current more 0.01 A initial contact resistance does not exceed 0.05 ohm; in the process of service life, it increases to 0.1 ohm, the great value of contact resistance can reach to 2 ohm. With the commutation of low currents (10 μA with 10 mV) initial contact resistance does not exceed 1 ohm, final - 10 ohm and great - 300-1200 ohm.

After the prolonged stay in air under normal conditions, the contact resistance increases.

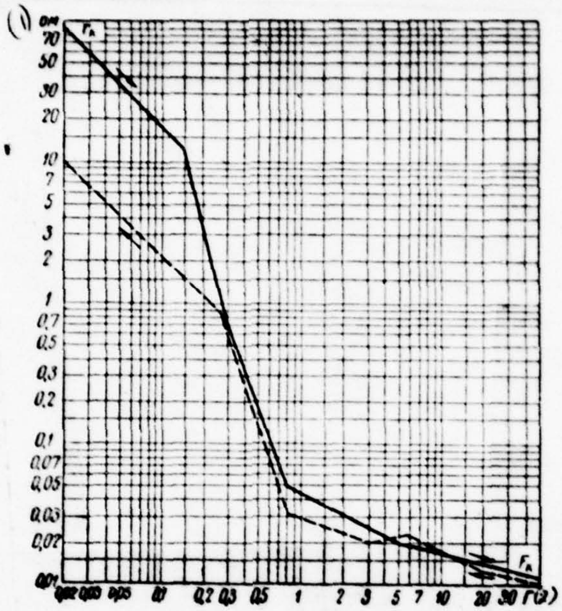

Fig. 18-2. Curved of contact resistance of palladium contacts.

Key: (1). ohm. (2) gf

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Figures 18-3 gives the integral distribution curves of contact resistance from the different materials through 28-32 and after 180-205-300 days of the stay under normal

conditions [18-18]. From these curves it follows that after 180-300 days the maximum value of the resistor/resistance of gold and palladium-silver contacts increases in accordance with 12 and 8.5 mΩ to 21 and 27 mΩ, while those of silver contacts - from 16 to 2000 mΩ.

In the process of work on contact surface, can be formed the coatings of fume (carbon), as a result of the combustion of organic vapors, or films. The resistor/resistance of carbon contacts is equal approximately to 10 ohm at a pressure in 1 g and approximately 3 ohm with 10 gs.

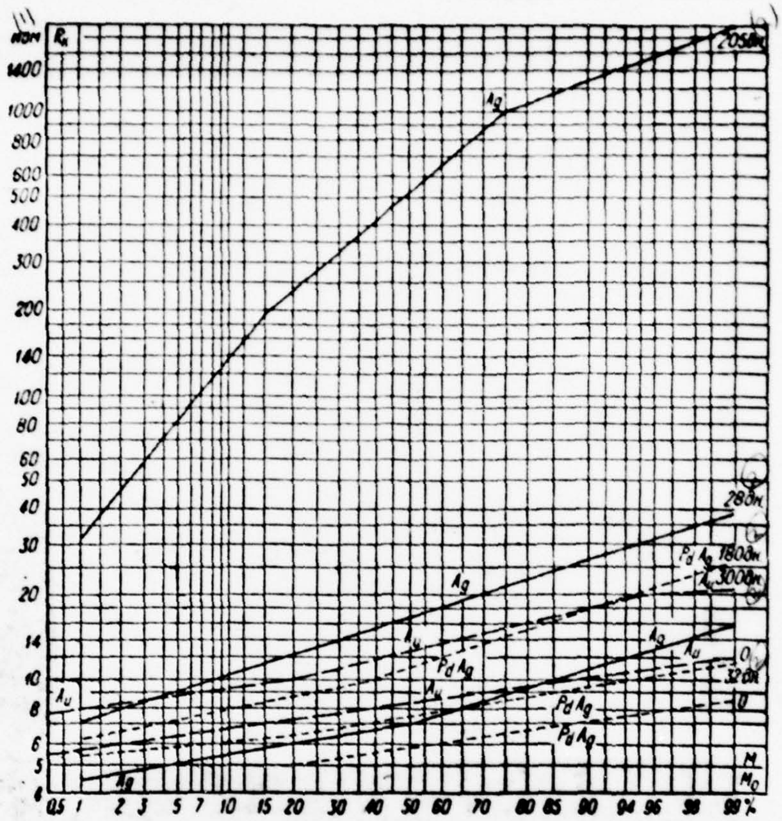

Fig. 18-3. Dependence of contact resistance on time after dressing.

Key: (1). mΩ. (2). dyn.

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18-3. Wear of contacts.

Wear or failure of contacts is caused by mechanical, chemical and electrical factors.

The abrasion of contacts occurs as a result of friction with slip and the impacts of contact surfaces in the process of closing of contacts. The value of abrasion depends on hardness and wear resistance of contact materials, form of contact surfaces, force of impact and pressure in contacts. The abrasion of the contacts of relay as a result of small mechanical effort/forces does not usually have vital importance. Only with the very large number of functions ($>30 \cdot 10^6$) it is necessary to reject the application/use of pure/clean silver for contacts and to replace it by more solid wear-resistant alloys.

The electrical discharges, which appear during interrupting and closing/shorting, are the main reason for two fundamental forms of the destruction of the contacts: chemical (corrosion), connected with the oxidation and other

reactions at high ambient temperatures, and physical, so-called erosion, of the connected with the phenomena physical character (melting, the evaporation, the atomization/pulverization of material), which occur on working contact surfaces. Erosion is usually accompanied by the transfer of metal from one contact to another and is especially pronounced with direct current.

With alternating current of low frequency (50-500 Hz) the phenomenon of erosion is expressed considerably weaker as a result of the mutual balancing of a quantity of transferred metal. With the commutation of high-frequency currents, the erosion of contacts is considerably greater than with the commutation of the currents of low frequency, since at high frequency it is insufficient time for the deionization of air gap during the passage of the current through zero value. An increase in the velocity of interrupting contacts shortens the arcing time and it decreases the erosion with direct current. With alternating current high velocity of interrupting contacts increases overvoltages and the duration of arcing.

Corrosion and, in particular, oxidation frequently causes the formation of nonconducting films on contacts and the

time/temporary or complete disturbance/breakdown of the conductivity of contact.

Erosion and transfer of metal cause formation/education on one of the contacts of the outgrowths, but on the other of crater, which can in the course of time lead to a considerable change in the form of contacts and their ganging.

The transfer of metal is caused by the form of the discharges between contacts and depends, mainly, on the parameters of the electrical circuit in which the contacts work. Figures 18-4 schematically shows the character of erosion (transfer) of metal on contacts under the varied conditions of their work.

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The arc of interrupting and spark cause predominantly the wear of cathode (-) and the partial transfer of its material to the anode (+). Liquid bridges and short arcs of interrupting and closing/shorting, and also cold emission of cathode, on the contrary, give the wear of both cathode and the anode, but the evaporation of the latter because

of a considerable anode drop is usually no longer is observed the partial transfer of the material of the anode to cathode.

Besides reasons indicated above for the disruption of the work of contacts, are observed also sticking and sintering (cohesion/coupling) contacts (phenomenon of coherence).

Welding contacts is connected with high heating and melting of contact points. In low-power contacts the welding is observed in the capacitive circuits, which do not have the limiting resistor/resistances in which are created the conditions for the formation/education of high-currents discharge during closing of contacts.

Caking (cohesion/coupling) is observed with low voltages and at low contact pressure; it is caused by the metallic bridges, which are formed with the breakdown of the finest insulating film between contacts.

a) Erosion during interrupting of contacts.

If one assumes that for the reclosing time of contact t_p the contact area or pressure in contact changes according to linear law, then we will obtain [18-3]:

$$s = s_0\left(1 - \frac{t}{t_p}\right) (1) \text{или} \quad F_к = F_{к0}\left(1 - \frac{t}{t_p}\right),$$

Key: (1). or.

where s_0 and $F_{к0}$ is an area of contact and pressure in the contact prior to the beginning of the process of interrupting, i.e., with t = 0.

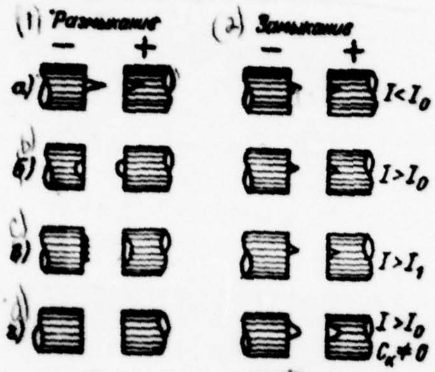

Fig. 18-4. The character of erosion (transfer) of metal on contacts under the varied conditions of their work: a) the current the less than maximum; b) the current of more maximum; c) current considerably more maximum; d) arc is extinguished by capacitance/capacity.

Key: (1). Interrupting. (2). Closing/shorting.

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Consequently, the dependence of contact resistance on time in the process of interrupting can be expressed by the following formula:

$$R_к = R_{к0} \frac{1}{\left(1 - \frac{t}{t_p}\right)^{\delta}}, \qquad (18\text{-}5)$$

where $R_{\kappa 0}$ is contact resistance to the beginning of the process of interrupting.

Differential equation for a circuit with the broken contacts will take the form

$$L\frac{di}{dt}+i\left(R+\frac{R_{\kappa 0}}{1-\frac{t}{t_p}}\right)=U. \qquad (18\text{-}6)$$

For the end/lead of the process of the interrupting when R_{κ} rapidly increases, let us disregard the value of the resistor/resistance of circuit and will replace the derivative di/dt with the relation of differences, i.e., let us assume

$$\frac{di}{dt}=\frac{0-i}{t_p-t};$$

then

$$L\frac{di}{dt}=-\frac{Li}{t_p-t}=-\frac{iR_{\kappa 0}}{1-\frac{t}{t_p}}\cdot\frac{L}{R_{\kappa 0}t_p}=-U_{\kappa}\frac{L}{R_{\kappa 0}t_p},$$

where U_{κ} is a voltage drop across contacts.

Substituting this expression in equation (18-6), we obtain:

$$U_{\kappa}\left[1-\frac{L}{R_{\kappa 0}t_p}\right]=U,$$

whence it follows that for end points of time, close to t_p, voltage on the contacts

$$U_{\text{к}}=\frac{U}{1-\frac{L}{R_{\text{к}0}t_p}}. \qquad (18\text{-}7)$$

If $L \approx R_{\text{к}0}t_p$, then voltage at the moment of opening can achieve the large values, sufficient for the onset of spark or arc between contacts.

The value of the energy, isolated in contact at each moment of time, is equal to:

$$A=\int_0^{t_p} U_{\text{к}} i\,di=\int_0^{t_p}\left[U-Ri-L\frac{di}{dt}\right]i\,dt=$$

$$=\frac{1}{2}LI^2+R\int_0^{t_p} i(I-i)\,dt. \qquad (18\text{-}8)$$

This energy more stored up magnetic energy L $I^2/2$, since during entire the reclosing time of contacts current source continues to supply circuit.

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At the last moment before the disruption of contacts the specific power, occurring per unit of the last/latter parts of the contact area,

$$\frac{P}{s}=\frac{R_{\kappa0}i^2}{s_0\left(1-\frac{t}{t_p}\right)^b}. \qquad (18\text{-}9)$$

When $t=t_p$ the value of the specific power strongly grow/rises and the material of contact at last/latter points is melted, forming between contacts liquid bridge from molten metal which as a result of the phenomenon, analogous to electrolysis, it will be thinned at the anode, thus far it is not broken, taking away the particle of the metal of the anode.

During interrupting of circuit with inductive load on contacts, appears high voltage, since

$$U_\kappa=U-L\frac{di}{dt}=U+L\left|\frac{di}{dt}\right|. \qquad (18\text{-}10)$$

In this case, between contacts, appears the gas discharge in the form of spark or arcs.

Arc discharge. In air the arc discharge is accompanied by the electronic and ionic conductivity of intercontact interval/gap with comparatively low gradients of electric potential (on the order of 10-20 V) and of current density to 10^4 A/cm².

Arc discharge is characterized by the falling/incident volt-ampere curve, and also the presence of plasma and cathode spot. The electrons, necessary for maintaining the discharge, enter from cathode in essence because of the thermionic emission. Temperature in the channel of discharge 3000-10000°C. For maintaining the stationary arc process, the voltage on contacts and arc current must not be less than the minimum voltage of arc (U_0) and of minimum arc current (I_0), depending on material contacts and medium. Values I_0 and U_0 for the number of contact materials are given in table 18-1.

The value of minimum arc current (I_0) is actually conditional, as so I_0 depends on the composition of gas medium, temperature and surface condition of contacts. Of the oxidized and covered with fume (" activated") contacts value I_0 can decrease several times. According to Holm's data, the arc by duration 10^{-5} s can appear with current $0.5I_0$ because of pair, that is formed during the blast of bridge. Value U_0 is equal about 8 V as a result of low ionization potential pair.

During arc discharge occurs considerable erosion and, as a rule, breaks down itself cathode, which is melted and evaporates because of the stagnation energy of the positive ions of gas and vapors of metal of the surface of cathode.

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The pairs of metal are condensed on the colder anode, in consequence of which is realized the partial transfer of metal from cathode to the anode. With high currents the thermal effect of plasma of arc on the anode is led to the preferred loss of the material of the anode [18-1].

Erosion of contacts with low currents.

Spark discharge. Spark discharge appears as a result of the breakdown of interelectrode interval/gap at a voltage more than 300 V, a pressure of the order of atmospheric (it is above) and a current it is less than I_0.

Spark discharge is characterized by very short duration (10^{-4}-10^{-8} s), the high current density, which reaches by 10^{6}-10^{9} A/cm^2, and very high temperature in the channel of discharge 10^{4}-10^{5} °C). The vapor pressure of metal in intercontact gap reaches to 400 at [18-34, 18-28].

Table 18-1. Minimum parameters of arc.

(1) Материал	(2) Ток I_0, а	(3) Напряжение U_0, в	(4) При $I = 1,5$ а и $U = 110$ в: (6) длина дуги l, мм	(7) длительность горения дуги t, сек	(5) Наименьший ток приваривания $I_п$, а
(8) Серебро в воздухе (влажность 45%)	0,3—0,4	12	1,2—1,3	—	20,5—24,5
(9) Серебро в чистом сухом азоте	0,8	13	—	—	—
(10) Серебро в азоте с 1% кислорода	0,32	12	—	—	—
(11) Серебро при +120° С	0,25	12	—	—	—
Серебро-медь 10%	0,25	12	—	—	—
Платина	0,7—1,0	15—17,5	—	—	15
Платина-иридий-10	0,8—1,1	20	—	—	—
Платина-осмий-7	2,5	—	—	—	—
Палладий	0,45—0,8	8—14	—	—	5
Палладий-серебро-40	0,5	—	—	—	—
Палладий-медь-40	0,6	—	—	—	—
Золото	0,38	11,5—15	—	—	—
Золото-никель-5	0,4	15	—	—	—
Родий	0,35	13	—	—	—
Вольфрам в воздухе	1,0—1,4	15—17,5	0,05	0,2	35—39
Вольфрам в азоте	0,9	16	—	—	—
Рений	0,3	12	1,4	5,3	—
Молибден	0,75—1,0	17	—	—	20—22
Никель	0,4—0,5	14	—	—	5—7
Медь в воздухе	0,4—0,6	12,3	—	—	—
Медь в водороде	1,3	18	—	—	—
Медь в азоте	0,6	14	—	—	—
Ртуть	3,0	22	—	—	—
Уголь	0,01—0,03	15,5—20	—	—	—

Key: (1). Material. (2). Current I_0, A. (3). Voltage U_0. V. (4). With I = 1.5 A and U = 110 V. (5). The minimum current of sticking $I_п$, A. (6). arc length l, mm. (7). the duration of arcing t, s. (8). Silver in air (humidity). (9). Silver in pure/clean dry nitrogen. (10). Silver in nitrogen with 1o/o of oxygen. (11). Silver with. (12). Silver-copper. (13). Platinum. (14). Platinum-iridium. (15). Platinum-osmium. (16). Palladium. (17). Palladium-silver. (18). Palladium-copper.

(19). Gold. (20). Gold-nickel. (21). Rhodium. (22). Tungsten in air. (23). Tungsten in nitrogen. (24). Rhenium. (25). Molybdenum. (26). Nickel. (27). Copper in air. (28). Copper in hydrogen. (29). Copper in nitrogen. (30). Mercury. (31). Carbon.

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In this case, the local overheating of contact surface of the end/leads of the discharge channel is led to the blast of molten metal with the formation/education of flames from vapors of the material of the contacts which produce the decomposition of the opposite surfaces of electrodes.

With small distances among contacts, breaks down itself the anode, at large distances - to larger degree cathode. With small amount of current due to the high resistor/resistance of circuit, spark avalanche is not formed, and at low air pressure is obtained the glowing (calm) discharge, accompanied by cathode sputtering.

With the commutation of capacitive and inductive circuits with currents, is less than I_0 and by voltages it

is less than 300 V (but is more than U_0) erosion is caused mainly by the short-term low-voltage pulsed discharges, created by electrostatic emission to small intercontact distances and which give positive transfer.

Bridge transfer. With the commutation of resistive loads, current, is less than I_0 and voltage is more U_0 or with current more I_0 and voltage is less than U_0, when are absent discharge phenomena, erosion is caused in essence by melting the contact points and by the extension of liquid bridges during interrupting of contacts with their subsequent mechanical disruption or evaporation in the form of blast by the accompanied formation/education pair, positive ions and electrons.

During closing/shorting the bridges appear because of extension by the electrostatic field forces (10^7 V/cm) of the particles of the softened contact metal, heated by the currents of electrostatic emission (10^{-10}–10^{-13} A) with very small intercontact distances ($<2 \cdot 10^{-5}$ cm). Bridge erosion during closing/shorting on several orders is less than during interrupting of contacts.

Bridges are formed usually with the current of more than 10 mA; however, unstable bridges are observed even with current 0.1 mA.

The length of bridges is within the limits approximately from 0.1 to 10 μm and depends on the material of contacts, value of current and atmospheric pressure. The diameter of bridges is approximately equal to their length. Because of good heat removal, the bridges maintain/withstand high current densities ($5 \cdot 10^7$ A/cm^2).

Figure 18-5 gives curves of dependence of the maximum length of the bridges, which are formed of the broken contacts from different materials, from the value of commutating current at different atmospheric pressures, obtained experimentally by M. A. Razumikhin [18-28].

Dependence curves of the most probable values of breakdown voltages from the distance between contacts from different materials at different atmospheric pressures are given in Fig. 18-6.

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During bridge erosion is observed total positive transfer. On cathode is formed the needle (peak), while on the anode the corresponding deepening (crater).

The erosion, caused by liquid bridges, does not depend on the inductance of circuit, but depends on the strength of disruptied current and can be expressed by the following formula:

$$G_{мост} = kI^n_{мост}, \quad (18\text{-}11)$$

where k - constant of the material of contacts and $I_{мост}$ - a current in contacts at the moment of the disruption of bridge.

According to Holm's last/latter data within the limits of current from 2 to 20 A value n = 2. The current strength at the moment of the disruption of bridge is determined by the following expression:

$$I_{мост} = I\frac{U - U_{кип}}{U}, \quad (18\text{-}12)$$

where I and U - established values of current and voltage of the circuit of contacts and $U_{кип}$ - the voltage, which corresponds to the boiling point of the material of contacts (for silver $U_{кип} = 0{,}7$ V).

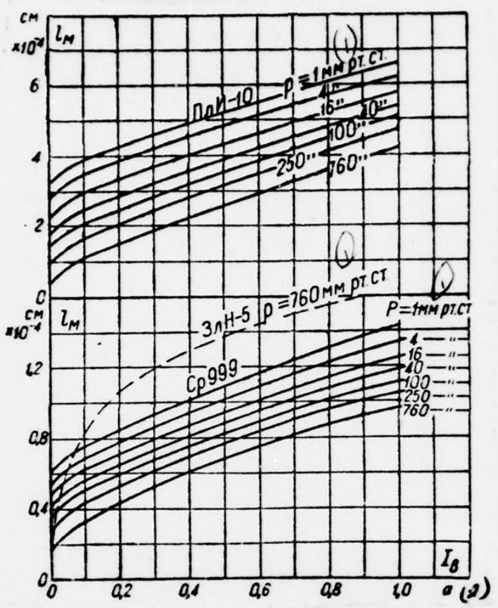

Fig. 18-5. Dependence curves of the maximum length of the bridges, which are formed on the broken contacts from different materials from the value of commuted current at different atmospheric pressures.

Key: (1). mm Hg. (2). A.

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The value of coefficient k with currents more 2 A is virtually constant and equal to $0.38 \cdot 10^{-12}$ cm^3/A^2, but with currents below 2 A it sharply falls.

Short arc. With low currents appear also extremely short-term transient arcs with duration on the order of 10^{-5} s (short arcs). These arcs appear with the very small inductance of order micro- or millihenry cause the transfer of the material of contact from the anode to cathode, the value of transfer depending on the inductance of circuit.

Short arc is called the arc whose length does not exceed 10^{-4} cm (mean free path of electrons). The arc of larger length ($\geqslant 10^{-2}$ cm) is called long or plasma.

Arc of very small duration can occur with the currents lower than limit of arc formation, if contact surface "is activated" as a result of the action of vapors of the organic matter, isolated by insulation (for example hydrocarbons), or it is contaminated by dust and oxide films.

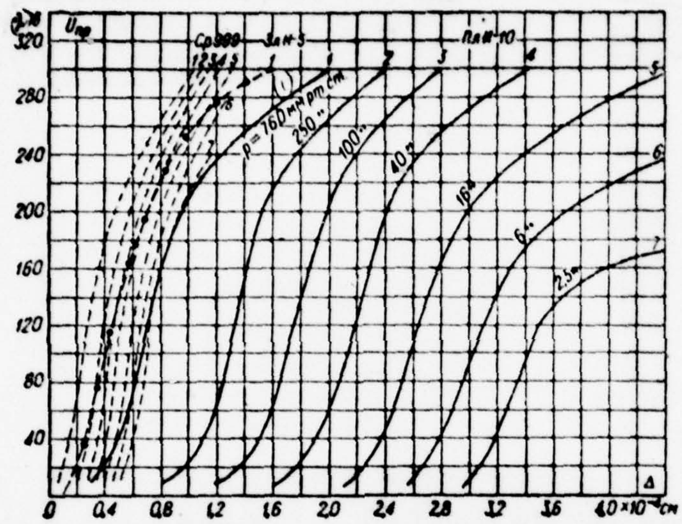

Fig. 18-6. Dependence curves of breakdown voltage from the distance between contacts at the different values of atmospheric pressure; - - - contacts from silver; —— contacts from alloy ZlN-5; — contacts from alloy PlI-10. 1 - atmospheric pressure 760 mm Hg; 2 - the same 250 mm Hg; 3 - the same 100 mm Hg; 4 - the same 40 mm Hg; 5 - the same 16 mm Hg; 6 - the same 6 mm Hg; 7 - the same 2.5 mm Hg.

Key: (1). mm Hg. (2). V.

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The activation of contacts frequently is observed in the airtight constructions of relay.

The limit of arc formation of the "activated" contacts descends to 0.1-0.03 A. The degree of erosion increases and contacts are cover/coated with dark coating (carbon black from carbon and particles of the metal of contacts), which at low pressures increases contact resistance.

Erosion of contacts with neutral currents.

Arc of interrupting. With neutral circuital currents ($I > I_0$ and $U > U_0$), appears arc, since the electrons, pulled out by electric field from cathode, have sufficient energy for the intense ionization of the molecules of the gas between electrodes. Gas ions bombard cathode and is caused its erosion. The losses of the metal of cathode are proportional to a quantity of electricity, which takes place through the arc, i.e., are approximately proportional to the strength of disruptted current. Furthermore, thermal action

of arc gives supplementary erosion, material of contacts it evaporates and is splashed, contact surfaces are oxidized.

In the presence of the arc between contacts, the current strength in the broken circuit is determined by the equation:

$$U = iR + L\frac{di}{dt} + U_{\text{д}}, \qquad (18\text{-}13)$$

where $U_{\text{д}}^{\bullet}$ - a voltage drop across arc (on contacts). A voltage drop across arc is the function of current $i_{\text{д}}$, of the distance between contacts and physical properties of the material of contacts.

Numerous investigations showed that with small distances between contacts a maximum voltage drop across arc in inductive active circuits can be expressed by the following formula:

$$U_{\text{д}} = U_0 + \frac{P_0}{i_{\text{д}} - I_0} \text{ (1) или } P_0 = (U_{\text{д}} - U_0)(i_{\text{д}} - I_0), \qquad (18\text{-}14)$$

Key: (1). or.

where I_0 and U_0 the minimum value of current and voltage with which appears the arc; P_0 - constant for this material, whose value is equal to the power, necessary for

maintaining the processes of ionization in arc.

For short arcs is known also another formula of the limiting current through the contact:

$$i_{\text{д}} = I_0 \frac{U_{\text{д}}}{U_{\text{д}} - U_0}. \quad (18\text{-}15)$$

The curved, limiting values of current and voltage lower than which under these conditions in circuit and purely resistive load cannot exist arc with plasma ("light arc"), are called maximum volt-amperes characteristic of arc.

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The presence of inductance in circuit sharply decreases the limiting arc characteristic, and capacitance/capacity, on the contrary, raises this characteristic.

Figure 18-7 gives maximum volt-amperes characteristic of arc for the contacts, prepared from different materials.

With a decrease in the arc length (i.e. the distance between contacts) its maximum volt-ampere characteristic descends. The dependence between the voltage and arcs current of minimum (virtually zero) length is called the

characteristic of minimum arc. This characteristic takes the form of the hyperbola whose asymptotes determine the value of current I_0 and of voltage U_0. The characteristic of minimum arc can be obtained oscillographically or constructed graphically from maximum volt-ampere characteristic.

Figures 18-8 shows the construction of the characteristic of minimum arc with the aid of maximum volt-ampere characteristic (1-2-3). The end/leads of the perpendiculars (shown dotted line), omitted from any point (1, 2, 3) of maximum characteristic on the axis of coordinates are connected between themselves by straight lines (lines of load). The lines of load are tangents to the characteristic of minimum arc, and envelope, constructed for a series of the lines of load, is characteristic of minimum arc.

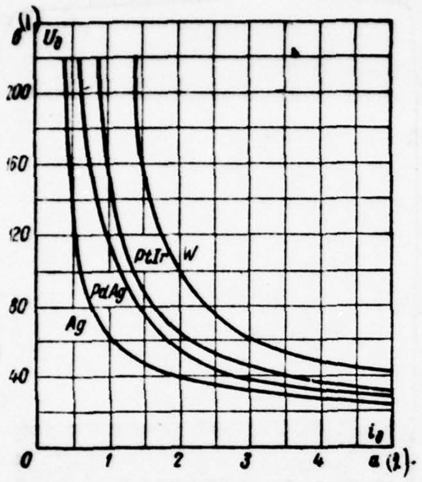

Fig. 18-7.

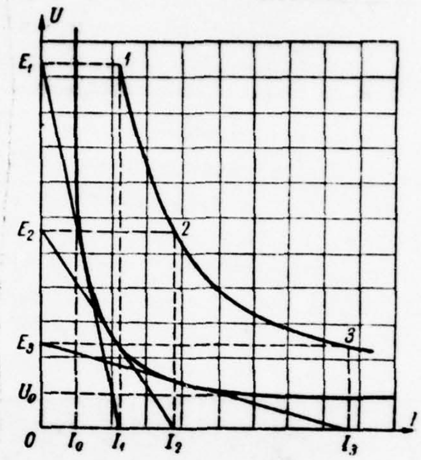

Fig. 18-8.

Fig. 18-7. Maximum volt-amperes characteristic of arc for contacts from different materials.
Key: (1). V (2). A.

Fig. 18-8. Construction of characteristic of minimum arc with the aid of maximum volt-ampere characteristic.

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During arc discharge the arc cf interrupting causes the evaporation of the metal of cathode. On cathode is formed

the crater, while on the anode outgrowth, i.e., during transition to arc discharge the direction of the transfer of metal changes by reverse/inverse (negative).

The erosion, produced by the combined action of the normal arc of interrupting and short arc, is expressed by the following formula:

$$G_g = \gamma_s q_s - \gamma_p q_p, \quad (18\text{-}16)$$

where γ_p and γ_s - coefficients of erosion for a normal and short arc; q_p and q_s - the quantity of electricity, transferred by normal and short arc.

The value of the coefficients of erosion depends on the density, thermal conductivities and the boiling points of the material of contacts and medium in which work the contacts: the type of gas, its temperature and pressure. The coefficient of erosion for a short arc γ_s, furthermore, it depends on surface condition and velocity of the motion of contacts.

According to different authors's data, within limits approximately from 1.5 to 8 A value γ_p for silver in air is equal to (0.33-0.43) X 10^{-6} cm^3/K.

According to Holm's data, with the current strength to 5 A for silver in air value γ_0 can be considered as constant and equal to $7 \cdot 10^{-6}$ cm^3/K. With an increase in the current more than 5 A γ_0 increases almost proportional to current.

The quantity of electricity, carried by arc, is equal to:

$$q = \int i(t)\,dt. \qquad (18\text{-}17)$$

In the case of purely resistive load, the quantity of electricity, carried by arc, can be approximately determined by the following equation:

$$q = I_{\text{д ср}}\tau \approx \frac{I_1 + I_2}{2}\tau, \qquad (18\text{-}17a)$$

where $I_{\text{д ср}}$ - an average/mean current to arc, I_1 - a current during the formation of arc, I_2 - a current with arc extinction, τ - an arcing time.

If we accept the velocity of the disagreement of the contacts of constant, then the arcing time

$$\tau = \frac{l_{\text{д}}}{v}, \qquad (18\text{-}18)$$

where l_A is an arc length and V - the velocity of the disagreement of contacts.

The values of quantities I_1, I_2 and l_A we find from volt-amperes characteristic of contacts with the aid of the line of load IBC (Fig. 18-9).

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Figure 18-9 gives volt-amperes characteristic of silver contacts. Point I corresponds to the locked state of contacts, point B - to the beginning of arc in current I_1.

With reduction in current in arc, the voltage increases, while at point C arc on will go out with current I_2. At point C, the line of load is tangential to volt-ampere characteristic, which corresponds to this arc length.

The inversion point of erosion during transition from pre-arcing region to the region of arc discharges is the

natural boundary of the division of low-power contacts into weak-current and moderately loaded.

With a further considerable increase in the current, the predominate thermal action of arc on the anode will involve a new change in the direction of the transfer of metal. This second inversion point is the boundary of the subdivision of contacts to moderately loaded and highly stressed (high-current). The character of erosion of positive and negative contacts depending on the current strength in the broken circuit (with $U \gg U_0$) it is shown in Fig. 18-10.

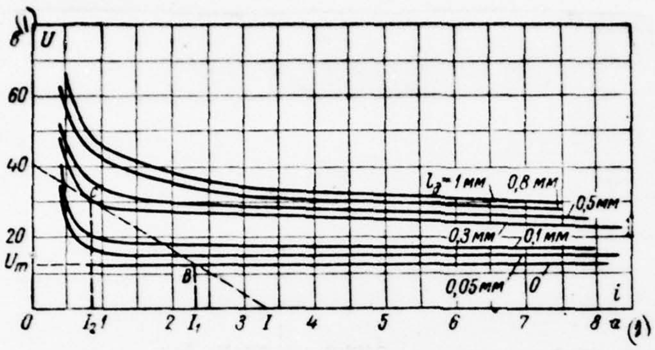

Fig. 18-9. Static volt-amperes characteristic of silver contacts.
Key: (1). V (2) A.

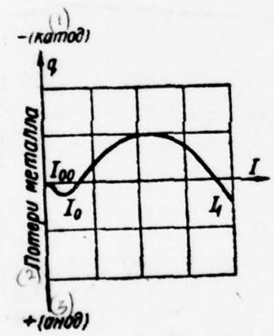

Fig. 18-10. Character of erosion of positive and negative contacts depending on the current strength.

Key: (1). cathode. (2). Losses of metal. (3). the anode.

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b) Erosion during closing of contacts.

The autoelectric emission. During the approach/approximation of contacts to each other on the distance on the order of 10^{-5} cm the voltage gradient grow/rises to $10^{5}-10^{6}$ V/cm and under the effect of electric field appears the autoelectronic emission of electrons from the surface of cathode, which causes spark. This spark cannot develop into other forms of discharge, since at the following moment of time contacts are closed. Electron stream from cathode causes small erosion of the anode, since the flow value and duration of its action are small.

But in the case of the presence of bouncing of contacts after the first closing/shorting appears the arc, which as a result of small distances can give larger destruction than during interrupting of contacts.

Short arc. The supplying installation wires and the contact springs of relay possess distributed capacitance. The

value of this capacitance depends on diameter and length of lead wires, their insulation and distance from adjacent wires or metal (grounded) boards or instruments.

During closing/shorting this capacitance/capacity gives the discharge through contacts in the form of short arc.

In parallel to contacts sometimes is included the spark-quenching duct, which consists of capacitance/capacity and resistor/resistance.

The connection/inclusion of capacitance/capacity in parallel to contacts decreases the erosion during interrupting of contacts and increases erosion during the closing/shorting of these contacts.

Changing capacitance value, it is possible to find the condition under which the transfer of metal to both sides will be balanced.

The quantity of electricity, which passes in the form of the short arc of closing/shorting, can be expressed by the following formula:

$$q_{з} = \frac{U - U_0}{r}\int_0^{t_{з}} e^{-\frac{t_{з}}{rC_{к}}}\,dt = C_{к}(U - U_0)\left(1 - e^{-\frac{t_{з}}{rC_{к}}}\right), \quad (18\text{-}19)$$

where U_0 - minimum voltage of arc formation; $t_з$ is a duration of the arcing of breaking; $C_к$ is a capacitance/capacity between contacts taking into account the capacitance/capacity of springs and lead wires; r is resistor/resistance of springs and lead wires.

If $\frac{t_з}{rC_к} \leqslant 1$, then

$$q_з = \frac{U - U_0}{r} t_з.$$

For tentative calculations Holm gives the empirical formula:

$$t_з = \frac{\tau (U - U_0)^2}{3 \cdot 10^3 \cdot r e^{\frac{\tau}{4 r C_к}}},$$

where τ - the constant of material, which depends on pressure in contacts and the velocity of their approach.

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For silver in air with v = 10 cm/s, we have τ = 2, also, with v = 1 cm/s - τ = 20.

General erosion of contacts during interrupting, caused by the action of liquid bridges, normal and short arc, is determined by the expression:

$$G = kI^2_{\text{мост}} + \gamma_s q_s - \gamma_p q_p.$$

18-4. Materials for contacts.

For the contacts of the relays, working with small currents ($<I_0$), are applied the precious metals: silver, platinum, palladium, gold and their alloys of the type of solid solutions.

For the contacts, working with the currents, which exceed I_0, most adequate/approaching are sclid and refractory metals and their alloys of the type of the solid solutions: tungsten, rhenium, molybdenum, platinum-iridium, palladium-silver, etc.

With high currents the metals and their alloys prove to be insufficiently wear-resistant, they rapidly are oxidized, they are fused, have large wear as a result of evaporation and sputterings and possess the ability to be welded. In such cases usually are utilized two-phase the systems, the so-called compositions.

The characteristics of different contact materials are given in Table 18-2 [18-1].

a) Silver.

Because of low contact resistance, high electrical conductivity and thermal conductivity, good technological properties and low cost/value, silver contacts received widest use almost in all types of relay.

Silver is applied three brands: commercially pure 99.9o/o and silver fusion from 7.5 or 10c/o of copper (90.0o/o). Under the action of electrical discharges, silver is oxidized (it grows dark), but silver oxides are conducting and easily dissociate ($\theta \approx$ 150-200°C). Therefore oxidation barely affects the magnitude (stability) of the resistor/resistance of silver contacts with the exception of the cases with very low contact pressure.

In the presence of oxygen and moisture, silver interacts with hydrogen sulfide whose traces always are in air, forming the black-grey film of sulfurous silver, which possesses very high resistor/resistance. This film can reach sufficient high thickness in order to destroy the conductivity of contact. Therefore silver contacts should not be applied in low contact pressures (less than 5 g and voltage less than 7-10 V.

The containing sulfur materials (for example, vulcanized rubber, ebonite, etc.) should not be placed near silver contacts. Dry sulfur dioxide does not operate on silver.

End Section.

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Table 18-2. Characteristics of materials for contacts.

(1) Наименование материала	(2) Марка	(3) Плотность γ, г/см³	(4) Температура плавления θ, °C	(5) Удельное электрическое сопротивление при 20° C ρ, ом. мм²/м	(6) Удельная теплопроводность λ, вт/см · град	(7) Предел прочности при растяжении $\sigma_{пч}$, кГ/мм²	(8) Твердость по Бринеллю H_B, кГ/мм²
(9) Серебро (10)	Ср999	10,5	961	0,0159	4,16	17—37	22—35
» электролитическое							110
Серебро-медь (11)	СрМ900	10,35	778	0,020	3,45	27—58	62
Платина (12) (13)	Пл99,8	21,45	1773	0,106	0,70	20—36	40—90
» электролитическая (14)							460—530
Платина-иридий	ПлИ-10	21,54	1780	0,245	0,40	39—69	110—180
» »	ПлИ-20	21,63	1815	0,30	0,17	60—100	170—250
(15) »	ПлИ-25	21,7	1840	0,33	0,3		220
Платина-родий (16)	ПлР-10	20,0	1825	0,19	—	33	80
Платина-осмий	ПлО-7	21,7	1820	0,40			250
Палладий (17) (18)	Пд99,8	12,16	1554	0,107	0,71	20—37	40—100
» электролитический (19)							200—400
Палладий-иридий (20)	ПдИ-10	12,74	1580	0,27	—	35—60	100—175
Палладий-серебро	ПдСр-40	11,46	1335	0,40	0,27	39—72	120—175
Палладий-медь (21)	ПдМ-40	10,4	1200	0,35	—	63	130—220
Золото (22)	Зл999	19,3	1063	0,022	3,1	14—26	20—70
» электролитическое (23)							65
Золото-никель (24)	ЗлН-5	18,3	1000	0,123	—	30—70	100—170
Золото-платина	ЗлПл-7	19,49	1080	0,102	—	20—60	40—120
Вольфрам (25)	(25a) Вч	19,3	3400	0,056	1,7	130—280	250—400
Рений (26)	—	21,0	3170	0,205	0,71	115—240	250—600
Молибден (27)	(27a) Мч	10,2	2620	0,052	1,46	70—200	140—300
Иридий (28)	И99,7	22,4	2454	0,055	0,59	23	170—275
Рутений (29)	Ру99,7	12,2	2450	0,082	—	—	220—360
Осмий (30)	—	22,6	2700	0,095	—	—	350—440
Родий (31)	Рд99,7	12,41	1966	0,049	0,88	40—100	115—390
(32) Родий электролитический	—	—	—	0,49	—	—	500—700
Никель (33)	Н1	8,9	1452	0,08	0,83	40—50	68—78

Key: (1). Designation of material. (2). Brand. (3). Density γ, g/cm³. (4). Melting point θ, °C. (5). Resistivity with 20°C ρ, ohm mm²/m. (6). the thermal conductivity λ, W/cm •

deg. (7). Ultimate tensile strength [1] $\sigma_{пч}$ kg/mm².

FOOTNOTE [1]. The smaller values of the limit of strength and hardness are related to the annealed metals, large - to those who were not annealed. ENDFOOTNOTE.

(8). Hardness on Brinell H_B kg/mm². (9). Silver. (10). electrolytic. (11). Silver-copper. (12). Platinum. (13). electrolytic. (14). Platinum-iridium. (15). Platinum-rhodium. (16). Platinum-osmium. (17). Palladium. (18). electrolytic. (19). Palladium-iridium. (20). Palladium-silver. (21). Palladium-copper. (22). Gold. (23). Gold-nickel. (24). Gold-platinum. (25). Tungsten. (26). Rhenium. (27). Molybdenum. (28). Iridium. (29). Ruthenium. (30). Osmium. (31). Rhodium. (32). Rhodium is electrolytic. (33). Nickel.

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A deficiency/lack in silver is its weldability with the commutation of high currents (>20 A).

The impurity/admixture of copper increases hardness and reduces erosion of silver, but during the formation/education of arc, the alloys of silver with copper strongly are oxidized, and contact resistance at low pressures becomes unstable.

Recently appeared silver fusion with cadmium, intended for medium loads. The application/use of silver fusions with cadmium for the contacts of small power somewhat decreases needle formation, but it gives no advantages in the relation to erosion and weldings.

Silver alloy with the small impurity/admixture of magnesium and nickel (~0.5o/o) possesses good spring and contact properties. This alloy is applied abroad for the production of the contact springs of miniature relays.

b) Platinum.

Because of the high parameters of arc, large noncorrosion property and the good technological properties, the platinum widely is applied under the severe conditions

of work and at low contact pressures (less than 15 g) for the contacts of relay. However, platinum and its alloys are inclined to the formation/education of bridges and needles with low currents. In pure form the platinum is applied comparatively rarely as a result of insufficient hardness.

The widest use use platinum alloys with iridium; these alloys are not oxidized, they very well resist arc formation and are characterized by high hardness (they yield to machining with the content of iridium to 30o/o). With inductive load by current 1A and voltage 50 V (with spark extinguishing) the service life of contacts of platinum alloy with 10o/o iridium approximately two times it is more than contacts from pure/clean platinum.

Platinum alloys with rhodium (10o/o) are less inclined to the formation/education of needles, than its alloys with iridium (10o/o).

Platinum possesses insignificant volatility and very weakly absorbs hydrogen. With medium loads (2 A) contact resistance of platinum contacts is small, but with low currents this resistor/resistance becomes unstable and changes within very large limits.

It is necessary to note that platinum and its alloys are scarce and expensive, they they must be applied only in the case of emergency.

c) Palladium.

One of the substitutes of platinum is palladium which in a series of properties closely is approached the platinum, but is considerably cheaper it.

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In comparison with platinum palladium of less struts in the relation to oxidation in air (grows dim at 500-600°C), but oxides of its not strut are decompose/expanded at higher temperatures. Noticeable difference is in the melting points and boilings, and also in volatility and cathode atomizability which for palladium is equal to 100 relative unity instead of 40 for platinum. Therefore contacts from palladium in work are cover/coated with black coating.

Platinum fusion from 7o/o Os possesses the very high value of minimum arc current (2.5 A) and large hardness (250 kg/mm²). Palladium has in comparison with platinum and silver the very small current of sticking, and considerably smaller coefficient of erosion with the arc of interrupting. Tendency toward needle formation of palladium is less than in platinum. Annealing in hydrogen for palladium is not applied that it dissolves hydrogen in large quantities.

The service life of contacts of palladium with greater loads approximately on 40o/o is less than platinum contacts. The cost/value of palladium is 2.12 times less than platinum, and if one considers that the specific gravity/weight of palladium is 1.87 times smaller than the weight of platinum, then easy to ascertain that the cost/value of palladium contacts is 4 times cheaper than platinum.

Besides commercially pure palladium, for the contacts of relay one should apply its alloys with silver (40o/o), by iridium (10o/o) and copper (40o/o). Contacts from palladium and its alloy with silver do not give noises in the

circuits of audio frequency (they do not possess microphonics). The cost/value of contacts of palladium fusion with silver is 9 times less than platinum.

However, the alloys of palladium with silver and especially with copper are characterized by the increased hardness, they cannot be used for the production of contacts without special heat treatment. In the annealed state palladium fusion with silver in hardness approaches platinum fusion with 10o/o of iridium.

d) Rhodium.

Rhodium is very good material for the contacts: it does not grow dim in air, it is characterized by good electrical and thermal conductivity, small volatility, infusibility and small plasticity. In the annealed form the rhodium has small hardness (115 kg/mm²), while in the galvanically precipitated state very large (500-700 kg/mm²).

As a result of the complexity of machining and high cost/value, the rhodium is applied only in the form of the

electrochemical coatings with thickness from 2 to 20 μ (with silver sublayer) and cannot be used with high currents.

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By large hardness, good wear resistance and high stability to erosion is characterized by the alloy of 30-40o/o rhodium with osmium which is applied in the jarring contacts of voltage regulators and does not develop stickiness.

The electrolytically precipitated rhodium has high hardness (800 according to Vickers), which provides the very small wear of contacts. Rhodium is applied for circuits with low voltage and low currents when is required large wear resistance (sliding contacts).

e) Gold.

Gold is not virtually oxidized in air, it possesses low contact resistance and is the best material for the

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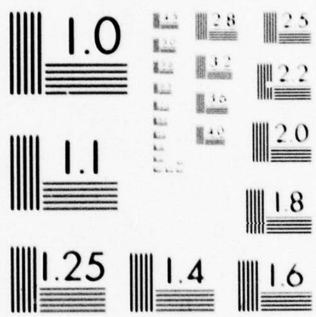
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

commutation of very low currents and voltages at small contact pressures (less than 10 g).

However, commercially pure gold has a tendency toward needle formation with small currents and not is useful for the commutation of current more than 1A, since it has the low parameters of arc, inclined to welding gives the large positive transfer of metal.

Furthermore, gold has small hardness and strongly it is abraded with the large number of commutations.

For the contacts of the relay of communication/connection, which commutate low currents, abroad sometimes is applied the ternary alloy, which contains 70o/o Au, 24o/o Ag and 6o/o Pt.

Auric fusion with 5o/o of nickel is characterized by from pure/clean gold the increased hardness, greater by wear resistance and smaller tendency toward needle formation. With respect to stability to corrosion, this alloy with normal temperature and small humidity is not inferior to gold and provides low contact resistance of contacts.

However, at elevated temperatures (+100°C) auric fusion with nickel with the commutation of low currents and voltages gives a considerably larger quantity of short duration failures, than commercially pure gold.

f) Tungsten.

As is known, stability to erosion of sparking contacts is raised with an increase in hardness and temperatures of melting, sublimation and boiling the material of the material of contacts, which is connected with an increase of the strength of its interatomic bonds. Therefore for the contacts, which commutate currents more than I_0 and increases voltages, most adequate/approaching are more solid and refractory metals and their alloys of the type of the solid solutions: tungsten, rhenium, molybdenum, platinum-iridium, palladium - silver, etc.

Tungsten is characterized by large hardness and brittleness, very high melting point and therefore several times it is more stable against erosion and transfer, than platinum.

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Contacts made of tungsten are not welded, they do not yield to abrasion and provide very large service life with high voltages and inductive loads (with current of up to 3-5 A).

Main disadvantage in the tungsten is its susceptibility of atmospheric corrosion with the formation/education of oxide and sulfide films; therefore contacts of the tungsten have high contact resistance and require large contact pressures (more than 40-60 g), especially with low voltages. Sometimes is observed failure of tungsten contacts after their prolonged stay under conditions of humidity and effects of vapors of phenol, formaldehyde, ammonia and other substances as a result of the intense corrosion of tungsten.

Contacts made of tungsten cannot be riveted directly to springs, they preliminarily are soldered or are welded on to steel or the copper "leg" which then is riveted to spring. The impurities by tungsten must not exceed

0.2-0.5o/o. More durable and more wear-resistant are machined (with longitudinal filament) contacts. They give also more constant contact resistance, than die-forge/stamped.

Molybdenum has smaller hardness than tungsten and lower minimum arc current. Oxides of molybdenum form loose residue/settling, as a result of which the conductivity of contacts can suddenly be destroyed. For protection against the formation/education of nonconducting films the contacts from tungsten and molybdenum one should place in vacuum, pure hydrogen or pure/clean nitrogen.

Large wear resistance with the load of 0.3 A - 160 V and very large service lives (10^{8} cycles) have contacts from carbide of tungsten with the small content of cobalt (ρ = 0.43 ohm • mm^2/m) [18-14].

Tungsten and molybdenum due to the susceptibility of atmospheric corrosion are unsuitable for operation under conditions of the tropical climate; under these conditions a good substitute of tungsten is the metal the rhenium, close to tungsten in its properties, but more corrosion resistant and more plastic [18-9; 18-21].

Contacts from rhenium have lower contact resistance under normal conditions; the value of this resistor/resistance comparatively is little affected after the prolonged stay under conditions of the tropical climate and marine atmosphere, and also after heating at elevated temperatures to 1000°C. However, the erosive stability of rhenium is considerably less than tungsten.

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g) The pairs of contacts from different materials.

In vibration apparatuses (voltage regulators, vibrapacks, etc.) with the currents, which do not exceed 1.2 A, and comparatively small pressures sometimes are applied the pair of contacts from various materials; for example, tungsten (on minus) and silver (on plus), tungsten and silver-nickel (SN40) or molybdenum-silver. In this case the film of oxides of tungsten is saturated with silver, which considerably decreases contact resistance and raises the reliability of the operation of contacts. At high currents and considerable pressures, is applied vapor carbide

tungsten-silver. Contact pair tungsten (on minus) and alloy palladium-copper (40o/o) (on plus) provides service life to $3 \cdot 10^{8}$ cycles of polar relays of type RP-4 with load 0.09 A -2 x 160 V in the telegraph conditions/mode of work (work in transmission).

h) Cermet compositions.

For the contacts, working under extra-heavy conditions - long time with large loads is necessary the material, which is characterized by large wear resistance, refractoriness, by small erosion, by a small tendency toward sticking, for high electro- and by thermal conductivity.

The combination of all these properties is not encountered in contact metals and their alloys, it can be reached only in compositions [18-1, 18-8, 18-20, 18-22].

Compositions are manufactured largely from the mixtures of two not fuse/alloyed between themselves components - the methods of ceramic metal (powder metallurgy), by sintering the mixture of the powders of metals without the

formation/education of liquid phase with subsequent machining (by forging, by rolling, etc.) or pressing of porous billets of the powder of refractory metal (W, Mo) with their subsequent saturation with more low-melting metal (Ag, Cu).

The durability of the composition against erosion is based on what with the melting of one component it is held by capillarity strengths in the pores (frame) of the second higher-melting component which to the same blocks the welding of contacts. Compositions, furthermore, do not have tendency toward needle formation.

High-melting frame can be formed not only by metals, but also by carbides, nitrides and even oxides of metals, since their electrical conductivity does not have in principle a value.

In the composition of silver-oxide of cadmium, the role high-melting that which comprises plays cadmium oxide. Cadmium oxide is characterized by high electrical conductivity, at the temperatures of arc, it is decompose/expanded explosion-like to oxygen and pairs of cadmium (770°C). This phenomenon, apparently, exerts the

blowing out and deionizing action on arc. Furthermore, outside boundary are applied the compositions of silver-carbide of tungsten, copper-carbide of tungsten, etc.

The physical properties of cermet compositions depend on the percentage of the content of comprising components.

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The content of refractory metal in compositions for contacts largely is within the limits from 40 to 85o/o through weight.

The fundamental parameters of compositions for contacts are given in Table 18-3.

Composition silver-nickel was developed for the contacts of relay with comparatively small contact pressures of instead of silver and platinum, unsuitable with large loads (it is more 2-3 A) as a result of large erosion and welding. In the especially critical cases for the exception/elimination of welding, is applied the pair of contacts from compositions silver-nickel and silver-graphite.

Composition silver-nickel (SN40, SN30) is characterized by small hardness, large plasticity (easily it is processed and is extracted in the form of wire) and small contact resistance: however it is less stable against erosion, than the composition SMO and SV.

The composition silver-oxide of cadmium (SOK12, SOK15) has high electrical conductivity, low contact resistance of contact and small hardness (easily rolls and is stamped).

Table 18-3. Physical parameters of some compositions for contacts.

(1) Наименование	(2) Марка	(3) Состав, %	(4) Плотность γ, г/см³ не менее	(5) Удельное электрическое сопротивление ρ, ом·мм²/м не более	(6) Предел прочности $\sigma_{пч}$, кГ/мм²	(7) Твердость по Бринеллю H_B, кГ/мм², не менее
(8) Серебро-никель	СН40	60—40	9,3	0,032	40	60
(8) Серебро-никель	СН30	70—30	9,5	0,025	38	55
(9) Серебро-окись кадмия	СОК12	88—12	9,0	0,027	42	45
(9) Серебро-окись кадмия	СОК15	85—15	9,2	0,030	40	50
(10) Серебро-окись меди	СОМ10*	90—10	9,2	0,025	—	50
(11) Серебро-кадмий-никель	СК22Н1	77-22-1	9,5	0,060	45	60
(12) Серебро-вольфрам	СВ30	70—30	12,0	0,023	65	70
» »	СВ50	50—50	13,1	0,027	51	100
(12) Серебро-вольфрам	СВ70	30—70	14,5	0,035	70	140
(13) Серебро-молибден	СМО60	40—60	10,0	0,027	66	120
(14) Серебро-графит	СГ3	97—3	8,7	0,024	22	27
(14) Серебро-графит	СГ5	95—5	7,9	0,030	16	22
(15) Серебро-никель-графит	СН29Г3	68-29-3	8,7	0,030	—	45
(16) Медь-вольфрам	МВ50	50—50	12,0	0,040	96	140
(17) » »	МВ70	30—70	14,0	0,050	130	180
Медь-графит	МГ5	95—5	6,0	0,047	—	15

Key: (1). Designation. (2). Brand. (3). Composition. (4). Density γ, g/cm³ are not less. (5). Resistivity ρ, ohm × × mm²/m are not more. (6). Limit of strength $\sigma_{пч}$ of kg/mm². (7). Hardness on Brinell H_B kg/mm², is not less. (8). Silver-nickel. (9). Silver-oxide of cadmium. (10). Silver-oxide of copper. (11). Silver-cadmium-nickel. (12). Silver-tungsten. (13). Silver-molybdenum. (14). Silver-graphite. (15). Silver-nickel-graphite. (16). Copper-tungsten. (17). Copper-graphite.

FOOTNOTE [1]. Instead of SOM8. ENDFOOTNOTE.

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Contacts from SOK12 and SOK15 are manufactured with diameter from 5 to 12 mm for loads from 10 to 100 A; with large loads they several times are more stable than contacts from silver.

The compositions of silver-molybdenum and silver-tungsten are more stable against erosion, but have considerably greater hardness and require greater contact pressures than compositions SN and SOK. Silver-molybdenum (SMO60) has lower electrical resistance and more easily is processed, than silver-tungsten (SV70). Contacts from the composition SMO are most suitable for a work with low voltages and neutral currents, while contacts of SV better maintain/withstand work with more high voltages.

Contacts from the composition of silver-oxide of copper SOM10 with high currents are more stable against erosion and corrosion, than contacts from SOK15.

The uniformity of properties and stability to erosion of contacts from compositions depends on the value of grains of powders; therefore the diameter of grains must not exceed 20-30 μ. Especially finely dispersed mixtures are obtained during the restoration/reduction of precipitated tungstenate or molybdenate of silver.

Common/general/total disadvantages of all compositions is the lowered/reduced electrical conductivity, in consequence of which one should apply them in the form of the laminae, soldered on to copper or steel foundations.

18-5. Size/dimensions and the form of contacts. Distance between contacts.

Depending on the form of contact contact surfaces, are divided into point, planar and linear.

To point contacts they are related:

To point contacts they are related: flat/plane-acute/sharp and spherical, to planar - cylindrical and brush (from the packet of plates), while to linear - roller and having the form of cylinder - plane.

If contacts work in the range of small power ($I < I_0$), then occurs erosion of contacts only from the action of spark. In these cases are applied most frequently point contacts, cone- plane, hemisphere-plane or two hemispheres by diameter to 2 mm. In this case, the cone or hemisphere is connected with the positive pole of current source. Erosion gives on the flat surface of cathode prominence/protuberances (needles), and on the surface of the anode of pocket (craters).

The contacts of flat/plane-acute/sharp form are applied that mainly, at low contact pressures.

At large power ($I > I_0$), are applied the hemispheric contacts of larger diameter (2-5 mm), planar or linear contacts.

The size/dimensions of contacts depend on the value of commuted current, operating mode, required the service life and permissible overheating.

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Table 18-4 gives the tentative size/dimensions of silver contacts depending on the value of prolonged limiting current.

For the savings of precious metals, one should apply the clad (composite) contacts, which are of copper foundation and the welded-on to it layer of silver or gold-nickel alloy with thickness 0.2-0.5 mm or bronze foundation with the layer of platinum or palladium (or their alloys).

The value of the smallest air gap between dead contacts is determined by current and voltage value, switched by contacts.

For providing the greatest service life of contacts, it is necessary that the distance among contacts would be more than arc length with the assigned load for this material of contacts.

With low currents (is less than I_0), the small distance between contacts is determined by the value of operating stress, it is more accurate by the value of testing voltage during checking of dielectric strength of insulation.

According to the existing norms for electrical apparatuses and installations with operating voltages up to 60 V testing voltage must be equal to 500 V eff.; with operating voltages from 60 to 250 V - 1500 V eff., with operating voltages from 250 V to 500 V - 2000 V eff. and with the voltages of more 500 V - $2U_p$ + 1000 V.

However, in the miniature/small and miniature relays, working in radio-electronic equipment, these norms cannot be maintained, since the distances between the current-carrying circuits of these relays are very small.

Table 18-4. Size/dimensions of contacts.

(1) Нагрузка I, а	(2) Диаметр контакта $d_к$, мм	(3) Завор между контактами[1] Δ, мм	(4) Высота контакта h, мм	(5) При двойном разрыве цепи	
				(6) диаметр контакта $d_к$, мм	(7) заворы[1] Δ, мм
(8) до 2	1—2	0,2—0,4	0,3—1,0	—	—
2—5	2—4	0,4—0,7	0,6—1,2	—	—
5—10	3—5	0,7—1,3	1,2—2,2	—	—
10—20	5—8	1,3—1,6	1,2—2,2	—	—
20—50	8—14	—	1,2—2,2	5—8	2 (0,8—1,0)
50—100	14—20	—	1,2—2,2	8—15	2 (1,0—1,2)
100—300	20—40	—	1,5—3,0	15—20	2 (1,2—1,7)
300—600	40—60	—	1,5—3,0	20—30	2 (1,7—2,2)

Key: (1). Load I, A. (2). Diameter of contact d_K, mm. (3). Gap between contacts [1] Δ, mm.

FOOTNOTE [1]. The gaps between contacts are given for voltages of up to 30 V direct current or up to 220 V of alternating current. ENDFOOTNOTE.

(4). Height/altitude of contact h, mm. (5). With dual chain cleavage. (6). the diameter of contact d_K, mm. (7). gaps [1] Δ mm. (8). to.

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Small and miniature relays with the voltages of 100-300 V operate almost exclusively in the anode circuits of small power; therefore for these relay it is possible to decrease the testing voltage.

The testing voltage of insulation of miniature/small relays under normal conditions with operating voltage of up to 100 V ampl. is taken equal to 500 V ampl. With the operating voltage of more than 100 V ampl., the testing voltage is established more than 3 U_p, but it is not less than 500 V ampl.

With the increased humidity (98o/o at +40°C) the testing voltage is taken as equal not less than 60o/o of the value of the testing voltage for this type of relay under normal conditions (0.6 U_{non}).

Under conditions of the lowered/reduced atmospheric air pressure of approximately 5 mm Hg with the voltage of more than 250 V ampl., appears the glowing discharge between the contacts of the open relays. The testing voltage of insulation at atmospheric pressure 41 mm Hg must not exceed 500 V eff, at the pressure 15 mm Hg. - 300 V eff. and at a pressure of approximately 5 mm Hg - 200 V eff. In

this case, the testing voltage of insulation must be higher than the worker and potential differences among any contacts and the winding of relay - are not less than to 50o/o.

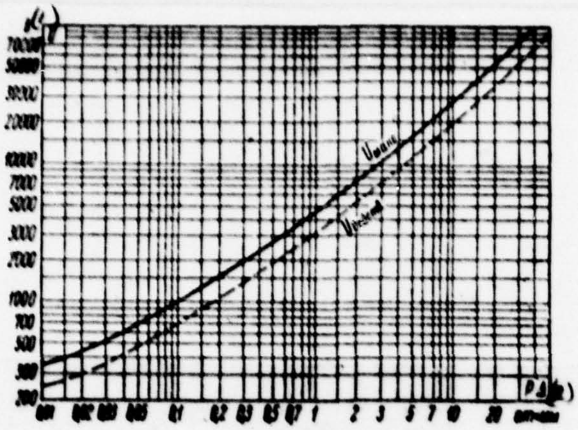

Fig. 18-11. Dependence curves of voltage with which breaks down air gap between two contacts of relay from product of pressure (in the atmosphere) on distance between these contacts (in mm).

Key: (1). V. (2). at x mm.

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For the determination of smallest distance between contacts Fig. 18-11 gives tentative dependence curves of the voltage by which breaks down the air gap between two contacts, from the product of atmospheric pressure (in the atmosphere) on the distance between contacts (in mm).

Figures 18-12 gives dependence curves of the amplitude of breakdown voltage from the value of atmospheric pressure (in mm Hg) at the different size/dimensions of air gaps, constructed with the aid of Paschen's curve. With the testing voltage of 500 V eff. and at normal atmospheric pressure, breaks down the air gap of approximately 0.06 mm; therefore the minimum clearance between contacts with $I < I_0$ it suffices to have about 0.1 mm. However, virtually the value of the testing voltage among contacts must be 1.5-3 times the less than breakdown; therefore the distance among contacts with operating voltage of up to 100 V usually is accepted not less than 0.15 mm.

In the high speed, highly sensitive and polar relays the minimum gap between contacts is necessary to decrease to 0.05-0.15 mm. With the gap between the contacts 0.04-0.08 mm, the testing voltage usually decreases to 350 V eff.

With the operating voltage in 220 V and low currents ($<I_0$) the small distance between contacts must be increased to 0.5 mm.

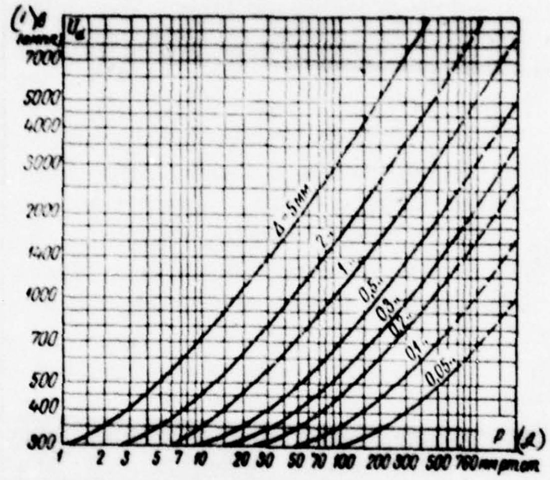

Fig. 18-12. Dependence curves of amplitude of breakdown voltage from atmospheric pressure with different values of air gaps.

Key: (1). V. (2). mm Hg.

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The disruptive ability of contacts grow/rises with an increase in the distance between contacts. However, the more effective method of an increase in the disruptive ability of contacts is the application/use of dual chain cleavage, i.e., the series connection into the circuit of two

contacts. Is explained this to the fact that in the latter case a cathode drop is doubled, and an arc-stream voltage changes approximately evenly on 10-50 V/cm. Figures 18-13 gives the curves of the dependences of the current, switched by contacts with voltage 60 V, on air-gap clearance between contacts at single and dual disruptions and different atmospheric pressures. From figure it follows that with the gap between contacts in 1 mm the introduction of dual disruption makes it possible to increase maximum rupturing current from 4 to 15.5 A. With an increase in altitude the limiting the breaking current of the contacts is decreased.

18-6. Electrical load and the service life of contacts.

The limiting value of circuital current of contacts is determined by the heating temperature, at which begins a decrease in the mechanical strength of the material of contacts.

The temperature of the overheating of the working section of contact surface (contact points) is determined by

the following formula:

$$\vartheta = \frac{\Delta U^2_{\text{к1}}}{8\rho\lambda}, \qquad (18\text{-}20)$$

where $\Delta U_{\text{к1}}$ - a voltage drop across the contacts with which begins a decrease in the mechanical strength of material;

ρ - specific strength of materials in ohm • cm;

λ - the coefficient of the thermal conductivity of material in W/cm • deg.

Mean temperature of contacts is lower than the temperature of the working section of contact surface; it is determined by the power, isolated in contact with rated current, and the heat emissions of contacts. The value of mean temperature of contacts must not exceed 200°C.

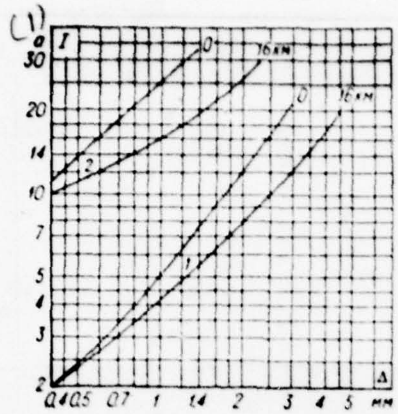

Fig. 18-13. Curved of dependences of current, switched by contacts with voltage 60 V, on air-gap clearance between contacts at single and dual disruptions and different atmospheric pressures. 1- single disruption; 2 - dual disruption.

Key: (1) A.

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The time constant of heating the working section of contact surface (contact "points) is very small (hundredth fractions of a second); therefore the temperature of the working section of contact surface manages to follow the changes in the current, which occur during transient processes in the switched circuit.

The allowed value of the current through the locked contact is equal to:

$$I_{доп} = (0,5 \div 0,8)\, I_{пред} = (0,5 \div 0,8)\, \frac{\Delta U_{к1}}{R_к}, \qquad (18\text{-}21)$$

where $R_к$ is contact resistance.

Contact resistance increases with a decrease in the contact pressure; therefore allowed value of the current through the contact decreases during lowering in the contact pressure.

If voltage on contact increases to $\Delta U_{к2}$, then contacts are welded on to each other. The values of quantities $\Delta U_{к1}$ and $\Delta U_{к2}$ for some materials are given in Table 18-5.

The greatest electrical load of contacts is determined from by maximum volt-ampere characteristic, which is the dependence between the boundary values of the stress and circuital current of direct current, with which can exist the stable arc between contacts.

Maximum volt-ampere characteristics depend on material of contacts, distance between them and environmental conditions (composition and the gas pressure in environment).

Working volt-ampere characteristic of contacts is obtained from maximum by the introduction of certain safety factor on voltage. With the assigned magnitude of current, operating voltage is taken 2-3 times of the less breaking stress, received from the maximum characteristic of contacts.

The permissible load of contacts is sometimes characterized by the amount of the permissible discruptted power. However, this value is not constant for entire range of currents and stresses of the performance characteristic of contacts.

Figures 18-14 gives dependence curves of the value of steady current from the greatest value of the voltage of circuit, by which another the arc goes out less than after 0.1 s, with the different distances between contacts and resistive load (for contacts from copper, silver and composition of silver-oxide of cadmium). These curves are constructed by R. S. Kuznetsov according to the results of the tests of I. P. Ermolaev and R. S. Kuznetsov taking into account Holm's data [18-4].

Table 18-5. Maximum voltage drop across contacts.

(1) Материал	$\Delta U_{\kappa 1}$, в (2)	$\Delta U_{\kappa 2}$, в (2)
(3) Серебро	0,08—0,10	0,35
(4) Золото	0,08—0,14	0,45
(5) Медь	0,09—0,13	0,45
(6) Платина	0,22—0,40	0,7
(7) Вольфрам	0,12—0,25	0,8

Key: (1). Material. (2). V. (3). Silver. (4). Gold. (5). Copper. (6). Platinum. (7). Tungsten.

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By dotted line are shown curves for the case of the location of the current-conducting parts, with which the arc can emerge the gap between contacts and be dilate/extended.

With the voltage, which exceeds by 10-15o/o of values, determined by the curves of Fig. 18-14 for this current, the friend between contacts it is not disruptted. The curves of Fig. 18-14 it is possible to also use in the case of the series connection of two or several contacts; in this case to each contact during interrupting, comes the line voltage, divided into the gap count of circuit.

For the commutation of direct current with $I \gg I_0$ and the voltage 220 V, and also alternating current with the voltages 400-700 V one should connect in series two contacts (two disruptive interval/gaps).

With alternating current up to 5 A, the voltage 220 V and to frequency 50 Hz the arc reliably is disruptted with the gap between contacts in 1 mm, with high currents this gap one should increase to 2-3 mm.

The character of electric arc with alternating high-frequency current approaches a character of direct current arc, since at high frequency insufficient time for the deionization of air gap during the passage of the current through the zero value.

The service life of the contacts of relay is determined that mainly, by their erosion.

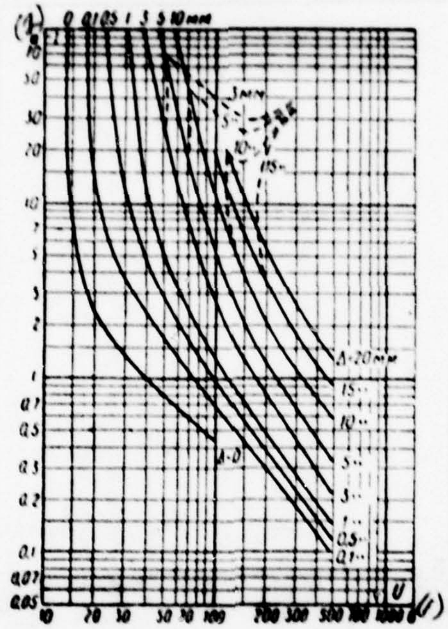

Fig. 18-14. Dependence curves of strength from DC voltage with which arc goes out with different distances between contacts.

Key: (1). V. (2). A.

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Erosion of contacts depends on many factors, namely:

a) value and type of load of the contacts (values of

current and voltage, the kind of the current, parameters of the switched circuit, form of the supply of power, frequency of the commutation of current, and so forth);

b) of size/dimensions, form and construction of contacts (single or dual contacts, the purity of processing and surface condition of contacts and so forth);

c) the construction of the magnetic and movable system of the relay (closing time and interrupting the contacts, presence of impacts and the fragment of contacts, pressure in contacts, the gaps between contacts, the value of the fitting-in of contacts);

d) of environmental conditions in which work the contacts (temperatures, the humidities and the chemical air composition, presence and composition of dust, vapors and so forth);

e) physicochemical properties and structure of the material of contacts (melting point and boiling, the hardness, the thermal conductivity, the parameters of arc and so forth).

The account of the effect of all these factors on erosion of contacts is extremely complex. Therefore at present no sufficient precise analytical methods of the calculation of the value of erosion of contacts. The given above approximation methods of calculation require the knowledge of the empirical coefficients of erosion whose value, obviously, also depends on all enumerated factors and therefore it has especially tentative value. Furthermore, it is necessary to consider that the contacts from precious metals and their alloys with comparatively light loads are abraded far unevenly on the test section of the surface. On one of the contacts, usually is formed fine/thin needle or outgrowth, on other deepening or crater. Therefore, after determining analytically the space of the worn and transferred to another contact material, it is not possible to find the real service life of contacts, which for the majority of loads is limited to the wedging of outgrowth in crater or to its sticking to the wall of crater.

By the service life of contacts (nominal service life), apparently, should consider the number of commutations (functions), which they can fulfill contacts with this electrical load before the appearance of systematic (frequently repeating) failures. Separate single failures

(short duration failures) after which the contacts long work exactly, can occur in the process of the normal operation of relay, and on account usually they are not accepted.

By the failure of contacts, generally is understood any disturbance/breakdown of their functions, i.e., both nonclosing/shorting of circuit as a result of very high contact resistance or the nonclosing/shorting of contacts (failure of I kind) and noninterrupting circuit due to weld either cohesion/coupling of contacts, arcing between them or the breakdown of the insulation between contacts (failure of II kind).

The number of commutations, which they can fulfill contacts to their complete output from system (complete failure), is called the limit of age of contacts.

Description of diagram to the account for failures I and for II kind in contacts during their testing for service life is given in [18-29].

Erosion of contacts is caused by a large quantity of factors whose part does not depend on the construction of relay; therefore the service life of the contacts of just

one type relay has large spread.

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If relay has two or several contact groups, then usually the service life of the different contact groups of just one specimen/sample of relay is different. Most strongly is distinguished the service life of the contacts, arrange/located in different series (for example, in the lower and upper contact groups). Is different also the service life of the closing, breaking and stud switches of one and the same relay and one and the same contact group.

Therefore for obtaining sufficiently reliable data, it is necessary to simultaneously produce testing during just one conditions/mode not less than 30-50 contact groups.

Figures 18-15 gives the differential distribution curve of the service lives of the contacts of relay of the type RES10 during resistive load 2 A - 30 V (N_0 = 123). Along the axis of ordinates is deposit/postponed the ratio of the number of refused contacts to a total quantity of tested contacts (d is a value of interval). Testing was conducted

by the frequency of commutations, equal to 5 Hz [18-29].

From this curve/graph it follows that the distribution curve of the service life of contacts is not subordinated to the normal law which is valid under the condition of the effect of a large quantity of independent and equally operating factors. Consequently, the action of a number of factors on the service life of contacts is connected with each other.

For the determination of the law of the distribution of the service life of contacts on Fig. 18-16 are constructed differential the distribution curves of the logarithm of the service life of the contacts of the relay of types RES9 and RES10 during the same load. Experimental data are deposit/postponed by crosses and small circles. From these curves it follows that the experimental points lie down sufficiently closely to the normal distribution curves of the logarithm of service life, constructed according to the statistical parameters of distribution, determined by experimental data.

Consequently, the value of the service life of contacts

can be characterized by two parameters: the distribution center (by mathematical expectation), which determines the most probable value of service life, and by the root-mean-square deviation from distribution center, which characterizes the stability of service life.

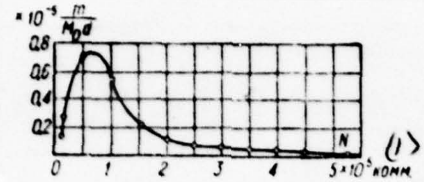

Fig. 18-15. Differential distribution curve of service lives of contacts of relay of type RES10 during resistive load 2 A - 30 V.

Key: (1). comm.

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For determining the smallest value of the service life of contacts, it is possible to use the simple rule k. and to determine the minimum value of the logarithm of the service live of contacts by formula (without taking into account of the confidence limits):

$$(\lg N)_{\text{мин}} = \overline{\lg N} - k\sigma_{\lg}, \tag{18-22}$$

where lg $\bar{N}$ is an average value of the logarithm of the service life s of the tested specimen/samples of the

contact groups of relay; σ_{lg} is the root-mean-square deviation of the logarithm of the service life and k - the quantile of normal distribution, which defines the boundaries of the service life within limits of which is found P o/o contacts of this type of relay.

The average value of the logarithm of service life is determined from the following formula:

$$\overline{\lg N} = \frac{\sum_{s=1}^{M_0} \lg N_s}{M_0}, \qquad (18\text{-}23)$$

where M_0 - a quantity of tested contact groups and s - a number of the specimen/sample of contact group.

The root-mean-square deviation of the logarithm of service life

$$\sigma_{lg} = \sqrt{\frac{\sum_{s=1}^{M_0} (\lg N_s - \overline{\lg N})^2}{M_0 - 1}}. \qquad (18\text{-}24)$$

Coefficient k depends on value P through the table of the quantiles of normal distribution (for P = 0.99 coefficient k = 2.326, and for P = 0.999 - k = 3.090) [1-31].

The maximum value of service life, possible for (100-P) o/o to relay, will be equal to:

$$(\lg N)_{\text{макс}} = \overline{\lg N} + k\sigma_{\lg}. \qquad (18\text{-}25)$$

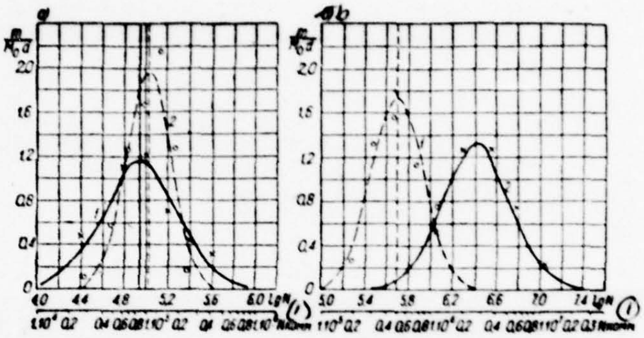

Fig. 18-16. Differential distribution curves of logarithm of service life of contacts of relay of types RES9 and RES10 during resistive load 2 A-30 V: a - relay of type RES10 1 - flooded by epoxy resin (M_0 = 122); 2 - with rolled in jacket (M_0 = 83); b - relay of type RES9. 1 - with silver contacts (M_0 = 40); 2 - with contacts from alloy ρIΣ - 10 with load 1A-30V (M_0 = 20).

Key: (1). comm.

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Figures 18-17 gives the integral distribution curves of the logarithm of the service life of the contacts of the relay of the type RES9 and RES10, constructed according to grouped data on logarithmic-probabilistic grid.

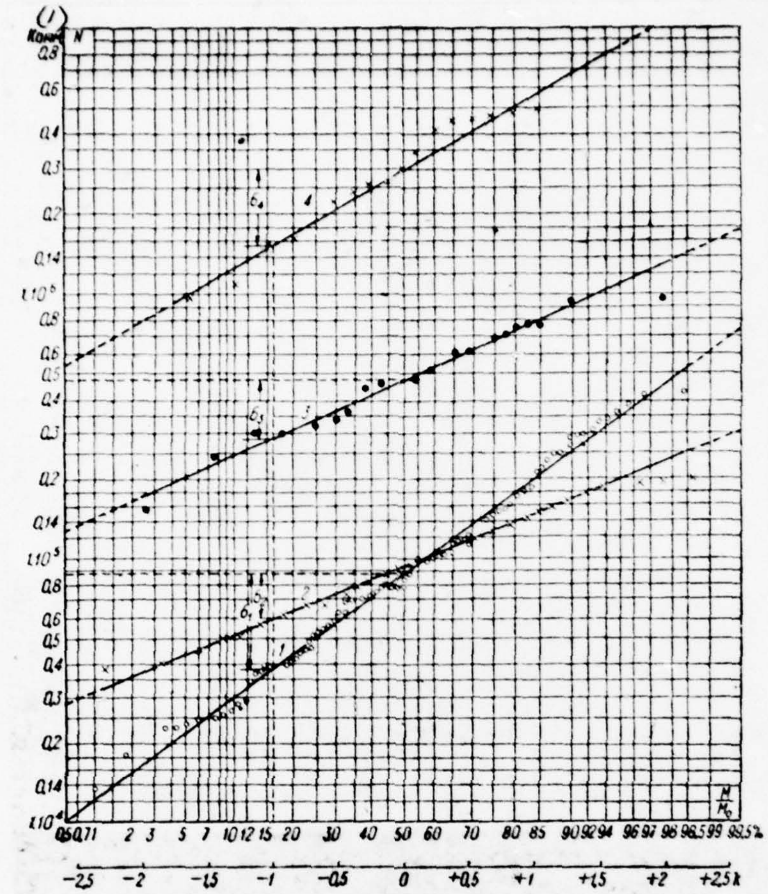

Fig. 18-17. Integral distribution curves of logarithm of service life of contacts of relay of type RES9 and RES10. 1 - the type RES10, flooded by epoxy resin, the load 2 A-30 V (M_0 = 122); 2 - the type RES10 with the rolled in jacket, the load 2A-30V (M_0 = 83); 3 - type RES9 with silver contacts, the load 2 A-30 V (M_0 = 40); 4 - type RES9 with contacts from alloy PlI-10, load 1 A - 30 V (M_0=20).
Key: (1). comm.

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(Quantity of tested contact groups of relays of the type RES10, flooded by epoxy resin, M_0 = 122, the rolled in relays M_0 = 83. Relays of the type RES9 with contacts from silver M_0 = 40 and with contacts from alloy PlI-10 M_0 = 20).

These curves in practice differ little from straight lines; consequently, the law of logarithm distribution of service life is close to normal law.

Certain deviation from straight line on the initial section of curves is explained by the presence of specimen/samples with the reduced service life because of the concealed/latent defects for random reasons.

Upper end of the curves is bent due to the "truncated nature" of distribution, since the service life of any contacts is limited.

Table 18-6 gives corrected values of the parameters of distribution, of the most probable and minimum service lives of types RES9 and RES10 (for k = 2.33), obtained as a result of processing experimental data.

From these data it follows that with the resistive load 2A-30V the most probable service life of the contacts of relays of the type RES10, flooded by epoxy resin (with N/N_0 = 0.5), is equal to 0.87 • 10^5 commutations; the smallest service life, which can have 1o/o of relay (corresponding P = 0.99 or N/N_0 = 0.01), is equal to 0.13 • 10^5 commutations and maximum service life (possible in 1o/o of relay) it is equal to 4.6 • 10^5 commutations. Consequently, the service life of contacts in 1o/o of relays of the type RES10, flooded by epoxy resin, into 6.7 less or 5.3 times of greater most probable service life (i.e. the service life of separate contacts changes 35.4 times).

The rolled in relays of the type RES10 have considerably smaller spread of the service life of contacts.

The most probable service life of the contacts of these relays with the load 2A-30V is equal to $0.89 \cdot 10^5$ commutations, minimum $0.31 \cdot 10^5$ commutations (2.88 times less than most probable) and maximum $2 \cdot 10^5$ commutations (2.26 times of more most probable).

Table 18-6. Values of the parameters of distribution, of the most probable and minimum service lives of relay.

(1) Тип реле	(2) Материалы контактов	(3) Нагрузка I, а	$\lg \bar{N}$	$\sigma_{\lg}$	$\frac{\sigma_{\lg}}{\lg \bar{N}}$, %	$(\lg N)_{мин}$	(4) Срок службы коммутаций	
							$\bar{N}\cdot 10^5$	$N_{мин}\cdot 10^5$
РЭС9	ПлИ-10	1	6,44	0,292	4,5	5,76	27,6	5,75
РЭС9	Ср-999	2	5,68	0,225	4,0	5,16	4,8	1,45
(5) РЭС10 (залито смолой)	ПлИ-10	2	4,94	0,356	7,2	4,11	0,87	0,13
РЭС10 (за- (6) вальцовано)	ПлИ-10	2	4,95	0,199	4,0	4,49	0,89	0,31

Key: (1). Type of relay. (2). Materials of contacts. (3). Load I, A. (4). Service life of commutations. (5). it is flooded by resin. (6). it is rolln.

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Consequently, failure of filling by epoxy resin of the jacket of relay of the type RES10 did not change the most probable service life of contacts, but it made it possible it to stabilize, as a result of which minimum service life increased almost 2.5 times.

The most probable service life of the contacts of relay of the type RES9 with contacts from alloy PlI-10

with resistive load 1A-30V is equal to 2.76 • 10^6 commutations, minimum 5.75 • 10^5 commutations (4.8 times less than most probable) and maximum 6.9 • 10^5 commutations (2.5 times of more most probable). Service life changes 12 times.

The most probable service life of relay of the type RES9 with contacts from silver (Sr 999) with the resistive load 2A-30V is equal to 4.8 • 10^5 commutations, minimum $1.45 \cdot 10^5$ commutations (3.3 times less than the most probable) and the maximum $9.7 \cdot 10^5$ commutations (2.02 times of more most probable). Service life changes 6.68 times.

Thus, with the resistive load 2A-30V the most probable service life of the contacts of relay of the type RES9 (of silver) is 5.5 times more than the contacts of relay of the type RES10 (from alloy PlI-10), the minimum service life of the contacts of relay of the type RES9 4.7 - 11.2 times of the more than contacts of relay of the type RES10.

Figures 18-18 and 18-19 shows differential the distribution curves of the logarithm of the service life of contacts (PlI-10) of the relay of types RES9 and RES10

(flooded epoxy resin) during different resistive loads (1, 2, 3, 4 and 5 A) and the voltage 30-32 V.

On these curve/graphs of the axis of the abscissas of the differential distribution curves, are arrange/located on the vertical lines, drawn at distances from each other, proportional to the logarithms of the corresponding currents of the load of contacts. Through points on these vertical lines, which correspond to the most probable and minimum service lives of contacts with these currents, are carried out straight lines 1 and 2, that show that with increase of the current of load the service life of contacts decreases.

These straight lines are to the dependence of the service life of the contacts of relay against the values of commuted current on logarithmic scale at the voltage 30-32 V and to resistive load. Consequently, within the limits of current load from 1 to 5 A they can be approximated by the formula of the following form:

$$N \approx \frac{N_1}{I^\alpha}, \qquad (18\text{-}26)$$

where N_1 - a service life of the contacts of relay with current into 1A and the voltage 30 V, I - amperage and α - the slope tangent of straight line to the axis of abscissas.

The values of quantities N_1 and for minimum, most probable and maximum service lives are given in Table 18-7.

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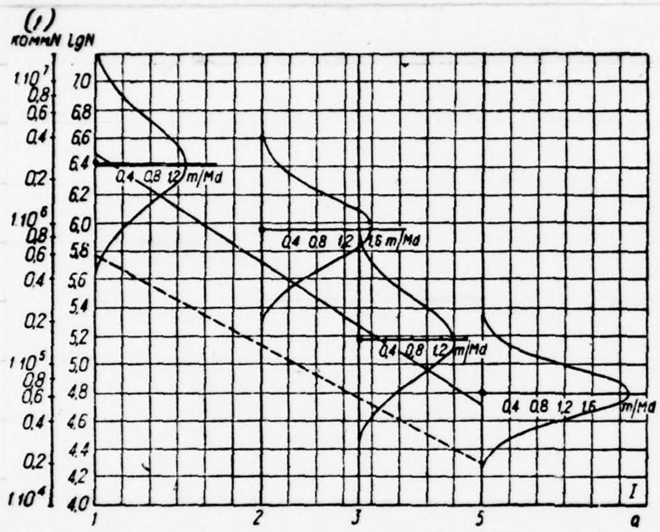

Fig. 18-18.

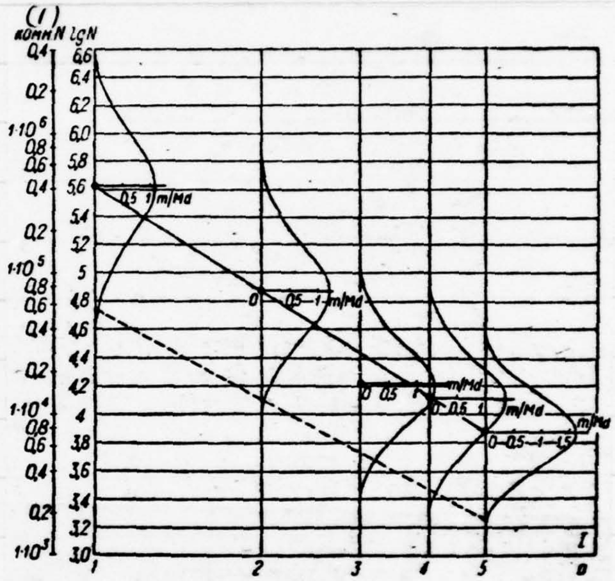

Fig. 18-19.

Fig. 18-18. Differential the distribution curves of the logarithm of the service life of the contacts of relay of the type RES9 during different active loads and voltage of 30-32 V.

Key: (1). Comm.

Fig. 18-19. Differential the distribution curves of the logarithm of the service life of the contacts of relay of the type RES10 during different resistive loads and voltage 30-32 v.

Key: (1). Comm.

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Figures 18-20 gives the curves of the dependences of the minimum, most probable and maximum service lives of the contacts of the relay of types RES9 (from silver) and RES10 (of PLI-10), flooded by epoxy resin on the amount of the switched power at resistive loads, constructed according to test data of relay at voltage of 30 V.

From these curves it follows that within the limits of the active load of contacts from 30 to 150 W the service life of the contacts of relay can be expressed as follows:

$$N \approx \frac{N_0}{P^\beta}, \quad (18\text{-}27)$$

where N_0 - a coefficient; its value is equal to the service life, which they would have contacts of relay with load in 1 W, if the dependence of the service life of contacts on section from 1 to 30 W was rectilinear, P - power in W and β - a slope tangent of straight line to the axis of abscissas.

Table 18-7. Values of quantities α, N_1, β and N_0 for the relay of types RES9 and RES10.

(1) Тип реле		РЭС9	РЭС10		РЭС9	РЭС10
(2) Срок службы	α	N_1	N_1	β	N_0	N_0
минимальный (3)	2,0	$5{,}8\cdot10^{6}$	$0{,}52\cdot10^{5}$	2,0	$5{,}2\cdot10^{8}$	$4{,}5\cdot10^{7}$
наиболее вероятный (4)	2,5	$27\cdot10^{6}$	$4{,}7\cdot10^{5}$	2,5	$1{,}3\cdot10^{10}$	$2{,}0\cdot10^{9}$
максимальный (5)	2,5	$80\cdot10^{6}$	$14\cdot10^{5}$	2,5	$4{,}2\cdot10^{10}$	$7{,}6\cdot10^{9}$

Key: (1). Type of relay. (2). Service life. (3). minimum. (4). most probable. (5). maximum.

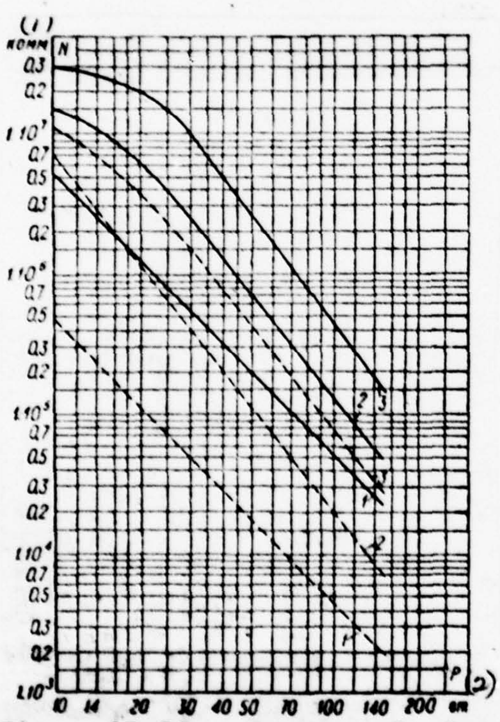

Fig. 18-20. Curve of dependence of the minimum, average and maximum service lives of the contacts of the relay of types RES9 and RES10 from the amount of the switched power. 1 - minimum service life; 2 - average life; 3 -

maximum service life; —— relay of the type RES9; - - - relay of the type RES10.

Key: (1). Comm. (2). W.

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The values of quantities N_0 and β for minimum, most probable and maximum service lives of the contacts of the relay of types RES9 and RES10 are given in table 18-7.

From data given in this table, it follows that the minimum service life of the contacts of relay of the type RES9 with silver contacts with resistive load inversely proportional to the square switched power and within limits from 30 to 150 W can be determined by the following approximation formula:

$$N_{\text{мин}} \approx \frac{5,2\cdot 10^{8}}{P^{2}} \text{ commutations,} \qquad (18\text{-}28)$$

a the most probable service life of contacts of relay of the type RES9 within these limits of power can be expressed the equation:

$$N_{cp} \approx \frac{1,3 \cdot 10^{10}}{P^{2.5}} = \frac{1,3 \cdot 10^{10}}{\sqrt{P^5}}. \quad (18\text{-}29)$$

Formulas (18-28) and (18-29) are obtained with resistive loads from 30 to 150 W and voltages of approximately 30 v; with other voltages the character of erosion of contacts, obviously, will change which, of course, will be reflected in the service life of contacts.

The greatest deviations from the calculated value of service life, obviously, one should expect for high currents and the voltages with which the arc is not disruptted (with this gap between contacts).

The tests, carried out on relay of the type RES10, showed that with resistive loads 0.3 a and 0.5 a and voltage 250 v most probable value of the service life of contacts is placed well on curves in the points of Fig. 18-2?, which correspond to power 75 and 125 W. With current 0.7 a and voltage 250 v, the minimum service life of contacts falls to 100 commutations as a result of the destruction of them by arc.

With light loads the service life of contacts is limited to the abrasion of the moving elements of the

relay and contacts; therefore life curves of contacts after $5 \cdot 10^{6}-1 \cdot 10^{7}$ commutations begin to be bent.

The analysis of the reasons for the failures of contacts from alloy plI-10 on the relay of types RES9, etc. showed that about 90o/o of all failures appears as a result of noninterrupting contacts due to the wedging of outgrowths one of electrode in the crater of another or due to welding of contacts. Exception are the contacts of relay of the type RES10 which with resistive load 1 A are 30 v of distance only 65o/o of failures on noninterrupting of contacts. Is explained this, apparently to the fact that the contacts of relay of the type RES9, with which decreases the value of outgrowths or break needles.

For an increase in the service life of contacts, it is necessary to find wear-resistant contact materials with smaller tendency toward needle formation.

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With inductive load the service life of contacts sharply decreases, since increases duration of arcing and the energy, isolated on contacts. The latter depends on the

amount of the switched power, time constant of circuit and eddy current losses in the switched magnetic system.

The nominal value of commuted current with inductive load (τ = 0.07 s) must be two or three times less than with resistive load.

With an increase in the ambient temperature from +20 to +(100-125)°C service life of the contacts of airtight relays decreases on the average two or three times as a result of an increase in the concentration of the organic vapors, isolated by insulation. At the lowered/reduced atmospheric pressure is facilitated the ionization and is impeded the recombination of particles due to an increase in the mean free path of electrons. The process of sputtering of material of contacts is amplified, which also facilitates ionization and the maintenance of the specific density of positive space charge in zone about cathode. The latter contributes to an increase in electron emission of cathode.

A change in the conditions of arc extinction is led to an increase in the quantity of electricity, passing through the arc and to an increase in the energy, which

is isolated in arc with an increase in the height/altitude in the process of disruption.

At altitude 30 km, the value of the current, switched by contacts, decreases approximately two times [redacted] [1-17].

18-7. Special constructions of contacts.

Recently receive wide acceptance the high speed (instantaneous) contacts of drain action - microswitches. In these constructions with an increase in the effort/force more than certain value the contact by jump passes of one position to another. Contacts are silver, pressure in contact of approximately 40 g. The wear of the contacts of drain action as a result of high rate of disruption is considerably less than usual contacts. This makes it possible to increase the values of the disruptted power of the contacts of drain action approximately 10 times, to 1200 volt-amperes with voltage 220 V and service life to $5 \cdot 10^6$ functions. However, virtually the service life of the high speed contacts does not exceed 10^5 functions.

For a commutation at a high speed of the circuits of high voltage to 30-50 kV at small driving power and with small gaps between contacts, are applied vacuum contacts.

The dielectric strength in vacuum contacts reaches to 100-200 kV/mm (theoretically to 600 kV/mm) instead of approximately 10 kV/mm in usual contacts with gap 0.1 mm and at normal atmospheric pressure.

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With fine vacuum (10^{-6}-10^{-5} mm Hg) the arc lasts very short time (rapidly it is disrupted), it has low energy and evaporates the insignificant part of the metal of contacts. This is explained by the cooling effect with instantaneous evaporation of the metal of contact point and a very rapid increase of the space pair in vacuum.

Therefore vacuum contacts allow/assume high current denisties, are not welded IMET [99sp04 - Institute of Metallurgy im. A. A. Baykov] considerably larger service life (with current to 10 A service life more than 10^6 functions, with currents from 10 to 100 A - more than 10^5 functions) [18-6].

the short interrupting time of arc (less than 10 μs) causes in inductive circuits large overvoltages. For decreasing overvoltage in parallel to contact is switched on the condenser/capacitor 0.05 μF with resistor/resistance 20 ohm. In vacuum there are no contaminations, which create film on contact surface; therefore contacts have low contact resistance, are not created noise and reliably they work at low contact pressures and high frequencies.

However, needle-formation connected with the formation/education of bridges during interrupting of contacts, in vacuum is not eliminated, but, on the contrary, it occurs even on such metals which as a result of oxidation in air do not give needle-formation.

Mechanical effort/force is transmitted to the slide contact through the flexible metallic diaphragm, sealed in in glass bulb, or magnetically.

At neutral contact pressures for contacts, are applied the tungsten and molybdenum.

For the elimination of corrosion and decrease in arc formation, contact system of relay sometimes is placed in the atmosphere of inert gases (nitrogen, hydrogen, argon and of the like). The dependence of the relative power, included by contacts without the formation/education of arc in the atmosphere of different gases, on thermal conductivity of these gases is given in table 18-8.

However, erosion of the material of contacts it is determined not only by a quantity of electricity, which passes during discharges, but also by interaction of the material of contacts with grey: by the absorption of gases, by the oxidation and by other reactions, or by the physical nature of gases, by ionization potential, by charge, by mass and by ion mobility, by thermal conductivity and other properties whose totality does not make it possible to establish/install any law governing effect of gaseous medium for erosion of contacts.

For the disruption of large powers are widely applied mercury contacts with the immersed steel float-cores or simple of rotary type (slope angle from 3 to 10°).

For an increase in the disruptted power, the

tank/balloon is filled with hydrogen and the disruption of current is arranged between the parts of mercury column (but not between electrode and mercury).

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Mercury contacts break currents to 10-25 A with voltages with respect 250 - 120 V of direct or alternating current. The service life of good constructions reaches $(1-2)\cdot 10^6$ interruptings.

18-8. Commutation of the low levels of currents and stresses.

In radio-electronic equipment and equipment for communication/connection, frequently is encountered the need for switching very low currents (from the hundredths of microamperes to dozens microampere) and very small voltages (from several microvolt to dozens millivolt).

The circuits in which occur/flow/last very low currents with very small voltages, frequently call "dry" circuits ("

dry circuits").

With the commutation of low levels of currents and stresses, the reliability of contacts is usually less than with the commutation of neutral and high currents, since surface films, forming as a result of the chemical interaction of the metal of contacts with gases and pairs of the environment (film of oxides, sulfides, hydrides, carbides, chlorides, film of organic origin and so forth), with small voltages not always break down and with low currents do not burn (they are Pnot burned).

With very small voltages (microvolts) it is necessary to also consider effect thermoelectromotive force, that appears in the circuit of contacts.

Consequently, the probability of the short duration failures (failures) of the contacts, which commutate the low levels of currents and stresses, is considerably more than in the contacts, which commutate normal loads. Therefore for the contacts, switching ery low currents and voltage, it is necessary to apply materials with minimum chemical activity and small thermoelectromotive force (paired with copper).

Table 18-8. Dependence of the power, disconnect/turned off without arc, on the thermal conductivity of gases.

(1) Параметры	(2) Газы					
	(3) воздух	(4) азот	(5) кислород	(6) углекислота	(7) водяные пары	(8) водород
(9) Относительная теплопроводность	1,0	0,3	1,8	2,5	5,0	17
(10) Относительная мощность, выключаемая без дуги	1,0	1,0	1,8	2,6	3,8	7,5

Key: (1). Parameters. (2). Gases. (3). air. (4). nitrogen. (5). oxygen. (6). carbonic acid. (7). water vapors. (8). hydrogen. (9). Relative thermal conductivity. (10). Relative power, disconnect/turned off without arc.

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It is necessary to note that with the commutation of low currents and voltages frequently occur the partial (incomplete) failures, with which contact resistance of contacts has very high value or slowly decreases from infinite to normal value.

The failures of contacts with low currents and voltages after one or several closing/shortings usually keep aloof and therefore they are frequently called "short duration failures".

Figures 18-21 gives the distribution curves of the number of refused contact groups of the relay of types RES6, RES8, RES9, RES10 and RES15 with contacts from alloy plI-10 from the number of commutations during switching of current 5 μA and voltage 50 mV, constructed SINCE Shtemberg and by D. V. Gaevskoy [redacted]. [18-30].

Along the axis of ordinates, is deposit/postponed relationship of the number of refused contact groups m to the total number of tested contact groups N_0.

from these curves it follows that in process of 10^5 commutations only 7o/o of contact groups of relay of the type RES15 not of the distance not of one failure (short duration failure). At the same time of relay of the type RES6 (with dual contacts from alloy plI-10 67o/o of contact groups they worked smoothly.

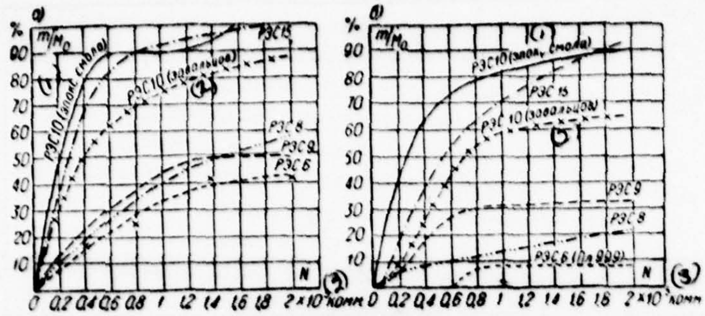

Fig. 18-21. Distribution curves of number of refused contact groups of relay of types RES6, RES8, RES9, RES10 and RES15 with contacts from alloy plI-10 during light loads (5 μA - 50 mV). a - n = 1 (failure-free operation); b - n = 10.

Key: (1). epoxy resin. (2). avalanches. (3). Comm.

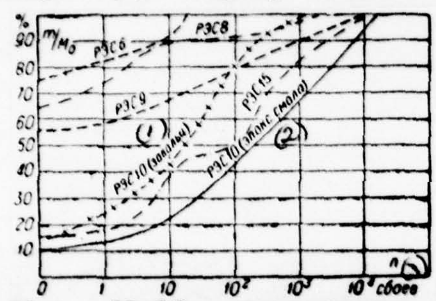

Fig. 18-22. Dependence curves of relative quantity of contact groups, which gave n and less than failures to 10^5 commutations.

Key: (1) Avalanche. (2). Epoxy resin. (3). short duration failures.

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The angle of the slope of the curves of Fig. 18-21 characterizes the rate of the increase of the number of contact groups, which have short duration failures or the intensity of the onset of short duration failures λ.

The tentative values of quantity λ for one commutation for one contact group within the limits of 10^4 commutations are equal for relay with contacts from alloy plI-10 of types: RES6 - $3.9 \cdot 10^{-6}$; RES8 - $5 \cdot 10^{-6}$; RES9 - $7 \cdot 10^{-6}$; RES10 - $18 \cdot 10^{-6}$; RES10, flooded by epoxy resin - $30 \cdot 10^{-6}$ and RES15 $22 \cdot 10^{-6}$ of short duration failures for one commutation.

For determining the quantity of short duration failures which possibly of the given contact group of the different types of relay in Fig. 18-22 are constructed the curves of the dependences of a relative quantity of contact group given n and less than short duration failures by 10^5 commutations.

From these curves it follows that 50o/o of contact groups of relay of the type RES10 (flooded epoxy resin) give to 200 short duration failures, and in 6o/o of contact groups, a quantity of short duration failures can reach to 10000 to 10^5 functions.

Of relay of the type RES6 with dual contacts from alloy plI-10 - 82o/o of contact groups, they give not more than 1 short duration failure for 10^5 functions, 8o/o of contact groups give not more than 10 short duration failures and not in one contact group was observed more than 20 short duration failures.

Figures 18-23 gives dependence curves of the mean number of short duration failures, which are necessary to one contact group from the number of functions (commutations) for the same types of relay.

From these curves follows that to 10^5 commutations of relay of the type RES15 it gives on the average of 850 short duration failures, relay of the type RES10 - 95 short duration failures, and a relay of the type RES6 - only 3 short duration failures.

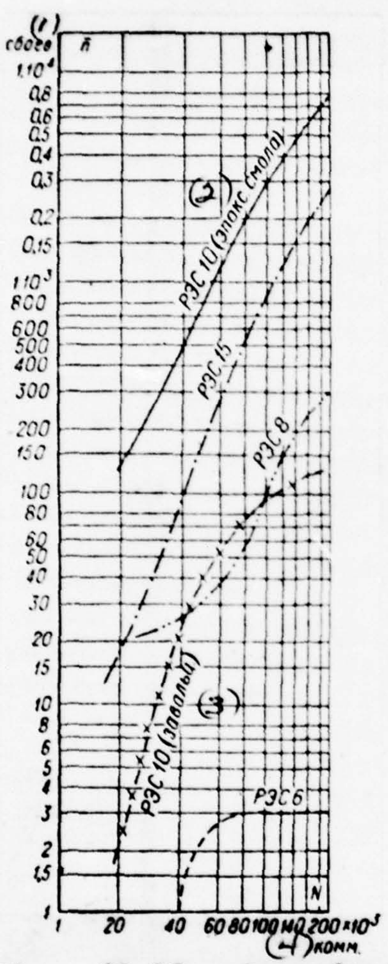

Fig. 18-23. **Dependence** curves of average number of failures (short duration failures), which are necessary to 1 contact group from number of commutations.

Key: (1). short duration failures. (2). epoxy resin. (3). avalanche. (4). Comm.

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For explaining the reliability of operation with low currents and the voltages of contacts, prepared from different contact materials SINCE Shtremberg, were carried out relay tests of types RES9 and RES10 with the contacts, prepared of 21 different materials and the relay of the type RES6 with contacts from 12 different materials.

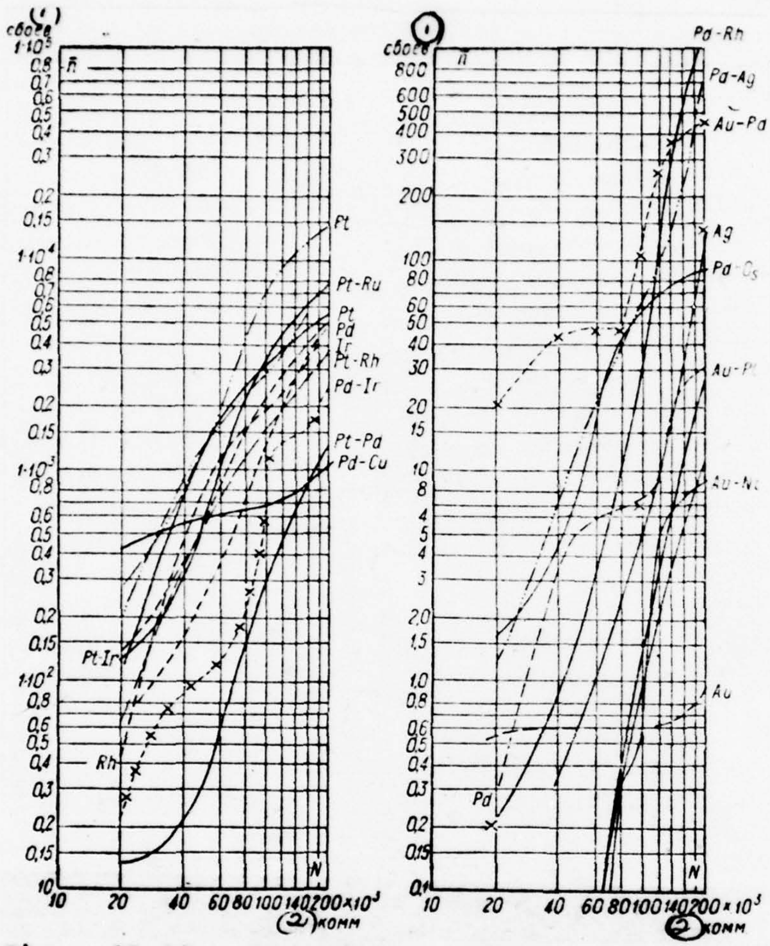

Fig. 18-24. Dependence curves of average number of short duration failures, which are necessary to 1 contact group from number of commutations for relay of type RES10 with contacts, prepared from different materials.

Key: (1). short duration failures. (2). Comm.

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Figures 18-24 shows the curves of the dependences of average number it is soy-bean, the incoming to one contact group on number commutations for relay of the type RES10 with the contacts, prepared from different materials.

From these curves it follows that the small number of short duration failures give the contacts from commercially pure gold (on the average 1 short duration failure on $2 \cdot 10^5$ of functions) and auric fusion with nickel (5o/o) (9 it is soy-bean on $2 \cdot 10^5$ functions).

It is necessary to note that in all tested types of relay occurred the single short duration failures, caused, apparently, as the incidence/impingement between the contacts of the wear products of the movable friction parts of the relay or extraneous particles from the surrounding contacts space.

A comparatively small quantity of short duration failures under normal conditions in the absence of porous gases give

also contacts from silver (5 short duration failures to 10^5 functions and 140 short duration failures on $2 \cdot 10^5$ of functions).

A great quantity of short duration failures is observed in contacts from platinum and its alloys with iridium (7000 and 3000 short duration failures to 10^5 functions).

Contacts of palladium and its alloys give somewhat smaller quantity of short duration failures, than contacts of platinum and its alloys. The contact resistance of the contacts, which commutate low currents and voltages, also depends on the material of contacts.

Figures 18-25 gives the curves of the dependences of the contact resistance of the breaking contact of relays of the type RES10 from contacts prepared from different materials, on the number of functions of relay.

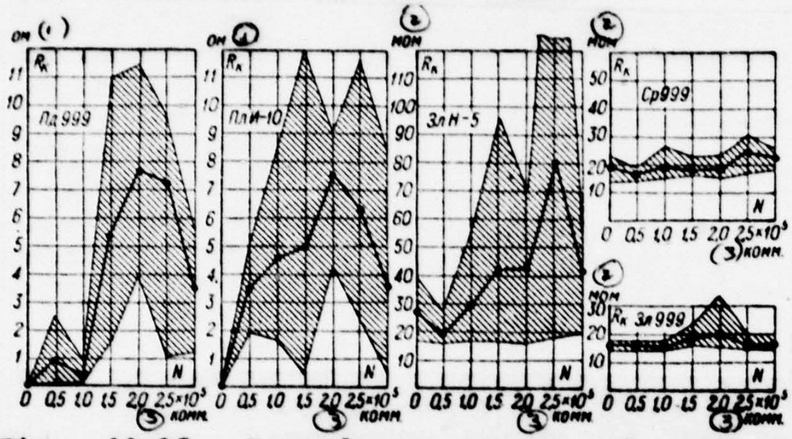

Fig. 18-25. Dependence curves of contact resistance of breaking contact of relay of type RES10 with contacts from different materials.

Key: (1). ohm. (2). mΩ. (3). Comm.

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Contacts of relay switched no electrical load, contact resistance was measured periodically with current 0.1 A.

From these curves it follows that average value of the resistor/resistance of gold contacts changes within very low limits (from 16 to 20 mΩ); the maximum value of resistance of these contacts does not exceed 34 mΩ (after $2\cdot10^5$ functions).

The resistor/resistance of silver contacts under normal conditions has a little high average value (from 19 to 25 mΩ) and somewhat larger spread (from 13 to 39 mΩ), but silver very sensitively to the action of sulfides under conditions of humidity (under the action of hydrogen sulfide silver is cover/coated with badly/poorly conducting sulfide films).

Average impedance of gold-nickel contacts varies from 19 to 43 (80) mΩ, and the limits of changes in the resistor/resistance of these contacts are sufficiently great (from 17 to 97 (202) mΩ).

The contact resistance of relays of the type RES10, prepared of palladium (CP) s nd the alloy of platinum with iridium (PLI-10) with light loads is considerably more than gold and silver contacts, and it oscillates within very large limits. Average impedance of the contacts, prepared from palladium and alloy plI-10, varies from 20-30 mΩ to 8 ohm, but great value of the resistor/resistance of these contacts reaches to 12 ohm.

The inspection of contact surfaces under microscope showed that after $2 \cdot 10^5$ the commutations of current 5 μA with voltage 50 mV on the contact surfaces, prepared from platinum, palladium and their alloys is formed the powder of dark color, which is arrange/located in the form of ring around service platform of contact, moreover separate granules of the powder are scattered over entire contact surface. This powder easily is rubbed from contact surface leaving no traces.

On contact surface, clearly is designated small area/site or the hole, which appears as a result of the abrasion of working contact surface.

The mechanism of the formation of powder on the contact surfaces, prepared from the materials of platinum group thus far is unknown. They assume that this powder is the products of polymerization of vapors of the organic vapors, which are isolated from insulation of relay (framework/body of coil, the enamel of wire and the like).

The products of polymerization are deposited on contacts in the form of the thin films of high resistance which in the work of contacts are rubbed into powder at operating

points. Most intensely this powder is formed on the contacts of airtight relays and relay, flooded by epoxy resin, because of the high concentration of organic vapors.

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On the contrary, with the opening of avalanche relays of the types RES9 and RES10 quantity of short duration failures (failures) of contacts considerably decreased. The small defect level of relay of the type RES6 (with contacts from alloy plI-10) is explained by the presence of dual contacts and detachable loose jacket.

A small quantity of short duration failures (failures) of an airtight relay of the type RES8, apparently, is explained degassification of parts and by higher pressure in contacts.

It is characteristic that on the contacts, prepared from gold and its alloys, is observed the very thin layer of powder, considerably smaller according to thickness, than on platinum contacts, but on contacts from silver this powder barely is formed.

A quantity of short duration failures (failures) of airtight relay with gold and silver contacts, on the contrary, is somewhat less than in the open relay, apparently, because of the impossibility of falling of dust from the surrounding space.

It is interesting to note that the abrasion of working contact surface in closed relays is less than in those who were opened. This phenomenon is explained, probably by decrease of the coefficient of friction as a result of formation of polymer films on contact surface.

With an increase in the ambient temperature to +(100-125) °C average quantity of short duration failures of the gold and especially gold-nickel contacts and palladium contacts increases considerably more than platinum-iridium ones. At the reduced temperature (from -40 to 60°C) an average quantity of short duration failures of gold-nickel and gold contacts considerably increases, z of platimum-iridium and palladium contacts, on the contrary, decreases.

A quantity of short duration failures of silver contacts both with that which was increased and especially

at the reduced temperature sharply increases, apparently, as a result of formation of sulfide films.

In the industrial, urban and rural atmosphere that 9which most harmful comprises, is hydrogen sulfide. The delay of contacts for 48 h into mean (concentration 3 mg/dm³) is equivalent to the action normal of urban or industrial atmosphere for 5 years. For the commutation of low currents and voltages, silver is unsuitable, since it under the action of hydrogen sulfide is cover/coated with the badly/poorly conducting sulfide films. Silver can be applied in voltages not less than 7 V.

able 18-9 gives contact resistance of contacts from different materials to (R_0), also, after their delay in the atmosphere of hydrogen sulfide (R_1), the breakdown voltages of plank (E_n) and the noise voltage (E_m), which appears on the contacts of relay as a result of the vibration of stand automatic telephone station with the operation of selectors [18-11].

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From data given in this table, it follows that after

the stay in atmosphere of hydrogen sulfide transient resistance of contacts of gold and palladium increases not more than by 45o/o, and the breakdown voltage of film does not exceed 0.2 mV. Of silver contacts under analogous conditions, contact resistance increases 733 times, and the breakdown voltage at a pressure in 5 G is equal to 0.7 V.

With small contact pressures (to 15 g) and the service life of contacts it is not more than 10⁵ function for the commutation of low currents and voltages it is expedient to utilize the silver contacts, galvanically covered with gold by thickness 3-5 μ or by solid gold by thickness 10 μ.

In this case, it is necessary to ensure sufficient density, strength and the purity of coating.

It is necessary to consider that even the application/use of gold contacts does not exclude the possibility of short duration failures, since on contact surface are deposited the products of the polymerization of organic vapors, and to the operating points of contacts can fall the wear products of the moving elements of the relay, dust and dirt particles from the surrounding relay

space. Furthermore, during the production cf relay on working contact surface, can be deposited the pairs of metals and flux, which are formed with scldering or victuals of contacts, different parts and the external jacket (jacket) of relay. In the presence of humid air and considerable lowering in the ambient temperature (to -40, -60°C). on contact surface is formed the very thin layer of hoarfrost (the "icing" of contacts) calling is certain quantity of short duration failures and failures of relay (to several percentages).

Table 18-9. Contact resistance of contacts and the breakdown voltages of film.

(1) Марка материала	(2) $F_к = 15$ Г R_0, мом (2)	(2) $F_к = 15$ Г H_2S R_s, мом (2)	$\frac{R_s}{R_0}$	(2) $F_к = 2$ Г $E_п$, мв (4)	(2) $F_к = 5$ Г $E_п$, мв (4)	(2) $F_к = 15$ Г $E_п$, мв (4)
Ср999	0,75	550	733	850	700	20,8
Зл999	0,9	1,3	1,44	<0,2	<0,2	<0,5
Пл99, 8	15	1,7	1,13	<0,2	<0,2	<0,5
Пд99, 8	7,2	9	1,25	<0,2	<0,2	<0,5
Вч	750	7500	10	9,9	4,8	120
Мч	9,5	450	47,5	990	120	5,55
Н1	25	110	4,4	<0,2	<0,2	0,77
СрМ900	1,72	8,52	4,95	650	350	42
ЗлН-5	7,5	9,5	1,27	<0,2	<0,2	5,6
ПлИ-10	23	23	1,0	<0,2	<0,2	0,57
ПлРут-10	31,9	31,9	1,0	<0,2	<0,2	0,98
ПдМ-30	26	31	1,19	10000	10000	4,6
ПдСр-50	16,7	26,6	1,6	—	—	1,15

Key: (1). Brand of material. (2). mΩ. (3). g. (4). mV.

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Therefore for providing for low resistor/resistance and reliable work of contacts with switching of low currents and voltages, it is necessary to manufacture relay under conditions of the exceptional purity, observed in the production of electronic vacuum devices, with the application/use of air conditioning. All parts of relay and especially contact system must be well degreased, cleaned with the aid of ultrasonic device and they are repeatedly washed in the distilled water from the least trace impurities.

Contemporary relays for special radio-electronic equipment usually have airtight performance for the exception/elimination of the possibility of the incidence/impingement of dust, of humid air, organic vapors and aggressive gases. The vacuum-tight sealing/pressurization is provided by the application/use of leading-out pins from Kovar alloy, isolate/insulated by glass insulating beads, and by soldering in the atmosphere of hydrogen or argon-arc welding.

Plastics, used for preparing the housing of coil and other parts of relay, and also the insulating sheets of winding and the enamel of wire must not during heating isolate organic vapors or aggressive gases.

Before the sealing/pressurization of relay, must be well degassed in vacuum thermostat at pressure not above 10^{-4} mm Hg and temperature +170°C and are filled by pure/clean nitrogen (with the impurity/admixture of 10o/o helium) dried to the dew point not above -65°C. For the exception/elimination of the possibility of the incidence/impingement of organic vapors to contacts in some

contemporary constructions of relay, is applied dual sealing/pressurization, i.e., the winding of relay also hermetically insulated from contact system.

However, they most reliably switch low currents and voltage the airtight magnetically controlled contacts (see §17-1). These contacts do not have rubbing parts, they consist of glass and metal and can be degassed at higher temperature (to +400°C).

During the commutation of the very small voltages (microvolt) it is necessary to consider the effect of thermal emf, which appear in the circuit of contacts as a result of the use of different materials and different temperature of the individual sections of this circuit. The greatest difference in the temperatures is observed usually upon the connection/inclusion of the winding of relay.

For the production of contact springs, are applied the alloys from nonferrous metals (white copper, bronze of different brands and so forth), leading-out pins of airtight relays are manufactured from Kovar alloy, contacts - from precious metals and jumpers from copper. Pure platinum has considerable differential thermoelectromotive force paired with

copper - 6 μV/deg (at +20°C), palladium - 12 μV/deg. Very small thermoelectromotive force have: iridium - 1 μV/deg, rhodium - 0.8 μV/deg and gold - less than 0.3 μV/deg.

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Platinum fusion with 2o/o iridium or with 1.5o/o mercury possesses zero of thermoelectromotive force [redacted] [18-9].

In order to avoid the distortion of the switched stress, value thermoelectromotive force in the circuit of contacts must not exceed several percentages from operating voltage. great value thermoelectromotive force in the circuit of the contacts of relay of the type RES10 reaches 500 μV, relay of the type RES9 - 200 μV and by relay of the type RES6 - about 100 μV. Therefore the contacts of relay of the type RES10 can switch voltage not less than 10 mV, relay of the type RES9 - it is not less than 4 mV and relay RES6 - it is not less than 2 mV.

The small value of the current, switched by contacts, obviously, is determined by the value of the stray current through insulation which must not exceed several percentages from operating current. If the minimum value of the

insulation resistance of contacts is equal to 10 MΩ, then the resistor/resistance of the switched load must be not more than 0.5 MΩ. With voltage 25 v, the small value of commuted current will be equal to 50 μA, with voltage 0.5 v - 1 μA and with 10 mV - 0.02 μA.

18-9. Reliability of the operation of the contacts of the open relays.

The reliability of the work of electromagnetic relays depends in essence on the reliability of the action of contact system. On automatic telephone station by capacitance/capacity into 10000 numbers it is mounted from 50 to 70 thous. relays which have to 500 thous. contacts. In the establishment of connection between two subscribers, participate about 170 contacts. If each of the contacts, available on this automatic telephone station, will give only one short duration failure (failure) in 10 years of work, then as a result daily at station up to 100 misconnections. Therefore the contacts of telephone relays must have extremely high reliability.

In equipment for communication/connection, and also in many equipment/devices of industrial automation are applied the largely open relays, which do not have individual dustproof jackets.

The group detachable jackets of instruments or block/module/units do not have packing/seals from plate virtually do not shield contact relay from the incidence/impingement of dust from the surrounding space (location).

Therefore for providing the reliable work of the open relays, it is necessary to ensure the large pressure in contacts, sufficient for the crushing of the dust particles and providing fitting-in of the surfaces of contacts to each other in the process of their closing/shorting.

The fitting-in of contacts contributes to the cleansing of operating points from dust and surface films, and also is driven out the operating point of contact from the point at which occurs the disruption of current and the erosion of surface.

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The path length of the fitting-in of contacts depends on the rigidity of contact springs and is approximately equal to:

$$Z_u = y\,\mathrm{tg}\,\varphi = y\frac{F_\kappa l^2}{2EJ} = \frac{3}{2l}\left(\frac{F_\kappa l^3}{3EJ}\right)^2. \quad (18\text{-}30)$$

Investigations showed that with an increase of the pressure in contacts a quantity of short duration failures decreases. During the tests, carried out in the dusty atmosphere to the total number of 500000 functions it was observed: 4500 short duration failures on 100 pcs. of relay at the contact pressure 5 g, 213 short duration failures at the pressure 15 g and only 2 short duration failures with pressure of 30 g.

The advantage of dual contacts is explained to the fact that the probability of the simultaneous short duration failure (contamination) of both contacts of one pair is very small in comparision with the probability of the short duration failure of single contact.

Investigations showed that the replacement on the automatic telephone station of single contacts dual, in spite of decrease in pressure on each contact, gives a

decrease in common number of short duration failures of the contacts of example 10-20 times; therefore at present almost all types of telephone relays have dual contacts.

Figures 18-26 gives calculated curves of the dependences of a probable quantity of short duration failures of contacts n to 10^6 cycles (functions) on the value of contact pressure for the single and dual contacts of the open telephone relays at the commutation of low currents and voltages. By solid line is constructed curve 2 for dual mechanically not connected contacts. By dotted line is shown curve for the dual contacts, arrange/located on one spring, split of end/lead.

From these curves it follows that the single silver contacts of the open telephone relays with contact pressure ~~8~~ 23 g can give to 35 short duration failures, while at dual contacts at the pressure 10 g on each contact it is possible to expect not more than 3.5 short duration failures by 10^6 cycles [1. 18-16].

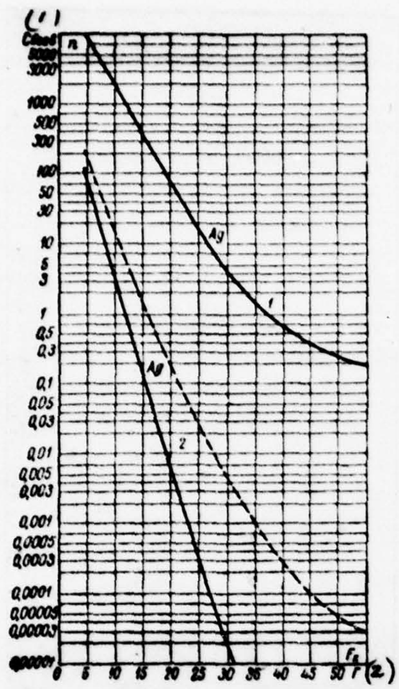

Fig. 18-26. Curved of dependences of probable quantity of short duration failures into work of contacts to 10⁶ functions on value of contact pressure. 1 - single silver contacts; 2 - dual silver contacts.

Key: (1). Short duration failures. (2). g.

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The questions of the calculation of the reliability of relay and contacts are presented above, into §1-24.

It is necessary to note that under operating conditions the cleanup of the unworn contacts of relay is unsuitable, since during cleanup they usually greater are soiled how they are cleaned. Dressing by file, by the emery paper or finishing damages (it scratches) it soils contact surface. Flushing by alcohol or carbon tetrachloride leaves coating (residue/settling) on surface, and rub by paper soils the contacts by short filaments. Is allow/assumed the cleanup of the contacts only by greasy hardened/tempered polished plate (measuring probe), washed (degreased) in pure/clean alcohol and by the worn through dry pure/clean suede.

The been charred, smoky and contaminated contacts after dressing and polishing must be also cleared by the steel washed probe, but it is necessary to consider that the cleaned contacts usually give more short duration failures, than new.

Surface films on the contacts, which commutate very low currents, can be opened, smoothly boosting on contacts of up to the onset of breakdown.

For the protection of the contacts of relay from dust are used metal or plastic jackets, moreover the slots between jacket and foundation of relay are closed by packing layers, they are painted by color/paint or fill with epoxy resin. In some constructions the edge of jacket is condensed by means of lapping/rolling.

However, this protection from dust brings more the harm than of benefit. In closed relays the wear (erosion) of contacts with nominal load and a quantity of short duration failures with the commutation of low currents and voltages is considerably more than in the open relays, as a result of the high concentration of organic and water vapors, isolated by insulation during heating of winding.

Furthermore, during fluctuations of temperature and atmospheric pressure inside relay is sucked humid air, and after the connection/inclusion of winding on contacts is condensed the moisture, which in certain cases is led to the formation/education of the water bridges between dead contacts. Under the action of a potential difference between contacts in water, form oxide of silver Ag_2O and is created path for the passage of current. The products of decomposition of contacts under the action of the passing

current gradually dry - they are condensed and form the fine/thin and brittle current-conducting bridge which can be retained long time and breaks down itself with impacts.

With the gap between the contacts 0.6-0.7 mm, the resistor/resistance of bridge is equal to 0.4-0.5 ohm and it can withstand for a long time current to 2.0-2.5 a.

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High relative air humidity within the closed types of relay is led also to a sharp decrease in the insulation resistance and creates conditions for the decomposition of the fine/thin wires of winding as a result of electrolysis with a potential difference among winding and housing more than 50 V.

During a considerable temperature decrease of relay, they reject due to the "icing" of working contact surface. Therefore in some types of closed relays for an increase in their reliability, it was necessary to make the ventilation windows, closed by three layers of grid No 0063 (having 7700 cells on 1 cm^2) for protection from dust [1. 18-29, article Gordon A. V., etc.].

Considerably more reliable are the contemporary airtight electromagnetic relays during production of which are applied special heat-resistant insulation, virtually which do not isolate organic and water vapors. These relays have vacuum-tight sealing/pressurization and are filled by dry inert gas.

However, airtight relays have more complex construction and large overall dimensions; for their production are required special insulating and structural materials, technology of the production of these relays is very complex. Therefore the cost/value of airtight electromagnetic relays many times is more than the open telephone relays.

Recently in equipment for communication/connection, begin to be applied cheaper vibrating-reeds relay, which have airtight contacts (see §17-1).

End section.

Chapter Nineteen

METHODS OF SPARK EXTINGUISHING.

19-1. General information.

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For a decrease in the wear of contacts and increase of the period of their service in circuits with reactive load, are applied the spark-quenching equipment/devices. The spark-quenching ducts usually consist of the resistor/resistance (linear or nonlinear) and the capacitance/capacity, included in parallel to load or contacts.

For purposes of spark extinguishing, can be used also quadrature winding on the magnetic circuit of electromagnet

or relay.

The action of the spark-quenching ducts consists in the fact that the magnetic energy, accumulated in circuit, is expend/consumed during interrupting not in the gap between contacts, but in the resistor/resistance of these ducts.

The identification of the parameters of the spark-quenching ducts must be produced so that the overvoltage, which appears on contacts at the moment of their interrupting, would be less than the voltage of the breakdown of air gap at given torque/moment.

For an increase in the service life, the transfer of the metal of contacts from the anode to cathode during interrupting is must as far as possible to be compensated for by the transfer in opposite direction during closing of contacts.

The breakdown voltage between the broken contacts depends on the value of air gap between them and atmospheric pressure. During interrupting between contacts, first is formed the bridge which is detonated under the action of the passing through it current; therefore the

small distance between contacts in the process of their interrupting is equal to the maximum length of bridge (l_m) before the blast.

The curves of the dependences of the maximum length of bridges on the current strength at different atmospheric pressures for contacts from different materials are given to Fig. 18-5.

With very small air gaps (less than the critical length 0.01 mm) breakdown voltage in spite of Paschen's law, are less than 300 V at normal atmospheric pressure.

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For determining the voltage of the breakdown of the very small air gaps, which are formed after the blast of the bridges between contacts, on Fig. 18-6 are given dependence curves of breakdown voltages from the distance between contacts from different materials at different atmospheric pressures.

With the value of commuted current, are more than 0.35 A for contacts from alloy ΡΠ- 10, more than 0.9 A for

contacts from alloy 31N-5 and more than 1 A for silver contacts at normal atmospheric pressure the voltage of the breakdown of minimum air gap is equal about 300 V [18-28].

Breakdown voltage for air gaps more than 0.01 mm can be determined by the curves Figs. 18-11 and 18.12.

Let us examine the basic concepts of spark extinguishing [19-1].

19-2. Spark-quenching ducts with linear resistor/resistances.

a) the connection/inclusion of resistor/resistance in parallel to the inductance of circuit (Fig. 19-1).

Voltage on contacts U_{κ}^{t} for the torque/moment of time, directly following after interrupting, will be determined from the solution to the equations:

$$0 = Ri + L\frac{di}{dt} + ri \quad \text{and} \quad U_{\kappa} = U + ri$$

on the condition that i = I = U/R with t = 0. Solution to these equations gives:

$$U_{\kappa} = U + Ire^{-\frac{R+r}{L}t} = U\left(1 + \frac{r}{R}e^{-\frac{R+r}{L}t}\right). \quad (19\text{-}1)$$

Great voltage on contacts will be at the first moment after their interrupting, i.e., with t ≈ 0. At this moment

$$U_{\kappa} \approx U\left(1 + \frac{r}{R}\right). \quad (19\text{-}2)$$

For excluding the of possibility of the appearance of a short-term discharge between contacts, it is necessary that U_{κ} will be less than the breakdown voltage of the smallest distance between contacts $U_{\text{пр}}$ or

$$U\left(1 + \frac{r}{R}\right) \leqslant U_{\text{пр}},$$

whence we find expression for value determination of the resistor/resistance of the spark-quenching duct:

$$r \leqslant \left(\frac{U_{\text{пр}}}{U} - 1\right)R. \quad (19\text{-}3)$$

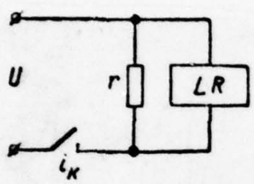

Fig. 19-1. Circuit diagram of resistor/resistance in parallel with the inductance of circuit.

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If consecutively with the winding of relay included supplementary **resistor/resistance** $r_д$ (Fig. 19-2), then

$$U_к = U\left[1 + \frac{r^2}{r_д(R+r)+Rr}\right] \qquad (19\text{-}4)$$

and

$$r \leqslant \left(\frac{U_{пр}}{U} - 1\right)\frac{R + r_д}{2} \pm$$
$$\pm \sqrt{\left(\frac{U_{пр}}{U} - 1\right)\left[\left(\frac{U_{пр}}{U} - 1\right)\left(\frac{R + r_д}{r}\right)^2 - r_д R\right]}. \qquad (19\text{-}5)$$

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
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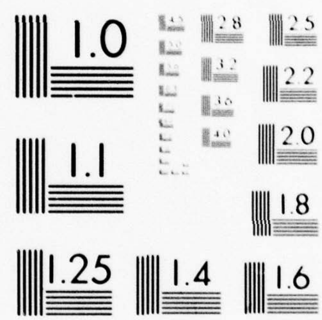
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

It is necessary to note that the connection/inclusion of resistor/resistance in parallel to winding increases the releasing time of relay, it leads to supplementary energy consumption and an increase in the current, disruptted by contacts. In the case of the presence of supplementary resistor/resistance $r_д$ changes also the time delay.

Condition of the absence of arc discharge.

The value of the current, passing through contacts, and voltage on contacts at the moment of disruption, obviously, are equal to:

$$i_к = \frac{U_к}{r} = \frac{U(R+r)}{Rr} \quad \text{and} \quad U_к = U\left(1 + \frac{r}{R}\right). \qquad (19\text{-}6)$$

Substituting these values $i_к$ and $U_к$ in expression for

the limiting value of the current through the contact (18-15), we find:

$$\frac{U(R+r)}{rR} \leqslant I_0 \frac{U\frac{R-r}{R}}{U\frac{R+r}{R} - U_0} \quad \text{or} \quad \frac{U}{R} r + U - U_0 \leqslant I_0 r.$$

Consequently, for the absence of arc discharge it is necessary, in order to the spark-quenching resistor/resistance

$$r \geqslant \frac{U - U_0}{I_0 - \frac{U}{R}}. \qquad (19\text{-}7)$$

where I_0 and U_0 are minimum values of current and voltage with which appears the arc on contacts from this material.

It follows to note that the smallest wear of contacts occurs when the small arc of interrupting is present, necessary for the compensation for the transfer, produced by liquid bridges and short arc.

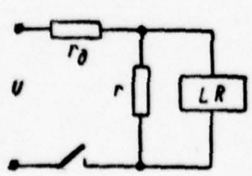

Fig. 19-2.

Fig. 19-2. Circuit diagram of resistor/resistance consecutively and in parallel to the inductance of circuit.

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b) the application/use of quadrature winding (Fig. 19-3).

If relay has quadrature winding, then, disregarding scattering (σ = 0 and $M^2 = L_1L_2$), we obtain for voltage on contacts after their interrupting the following expression [1-9]:

$$U_{\text{к}} = U\left(1 + \frac{r}{R}\cdot\frac{\tau_1}{\tau_1+\tau_2}e^{-\frac{t}{\tau_1+\tau_2}}\right) = \\ = U\left\{1 + \frac{rR_{\text{к}}}{R\,[R_{\text{к}} + (R+r)\,\nu^2]}e^{-\frac{t}{\tau_1+\tau_2}}\right\}. \tag{19-8}$$

In this formula

$$\tau_1 = \frac{L}{R+r},\ \tau_2 = \frac{L_{\text{к}}}{R_{\text{к}}} \quad \text{and} \quad \nu = \sqrt{\frac{L_{\text{к}}}{L}} = \frac{w_{\text{к}}}{w},$$

where $L_{\text{к}}, R_{\text{к}}$ and $w_{\text{к}}$ — inductance, resistor/resistance and the

turn number of quadrature winding.

Great voltage on contacts after their interrupting will be with t = 0; in this case

$$U_{\text{км}} = U\left\{1 + \frac{rR_{\text{к}}}{R\left[R_{\text{к}} + (R + r)\nu^2\right]}\right\}. \qquad (19\text{-}9)$$

In the case of the absence of shunt ($r = \infty$) the great voltage on the contacts

$$U_{\text{км}} = U\left(1 + \frac{R_{\text{к}}w^2}{Rw_{\text{к}}^2}\right). \qquad (19\text{-}10)$$

c) eddy-current effect, which appear in the magnetic circuit of load.

With the disconnection of the circuit of the inductive load of contacts (relay, electromagnet or throttle/choke) in its magnetic circuit are induced the eddy currents, which absorb certain part of magnetic energy and which convert it into heat.

Therefore magnetic circuit can be considered as secondary quadrature winding of relay, electromagnet or throttle/choke, which has one turn ($w_к = 1$).

Great of voltage on the contacts, which commutate relay with quadrature winding, according to formula (19-10), is equal to:

$$u_{нм} = U\left(1 \mp \frac{R_к w^2}{R w_к^2}\right) = U\left(1 + \frac{R_{мк} w^2}{R}\right). \qquad (19\text{-}10a)$$

where $R_{мк}$ — resistor/resistance to the eddy currents of the magnetic circuit of relay.

Virtually great voltage on contacts has high value, since the coupling coefficient of winding and core is less than unity.

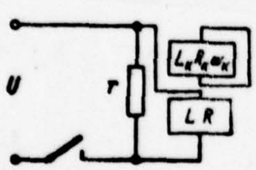

Fig. 19-3. Diagram of spark extinguishing with the application/use of quadrature winding.

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The magnetic circuit of the d-c relay usually consists of three parts; the core, which has round cross-section, the housings and the armature, which have rectangular cross section.

The resistor/resistance of these parts to eddy currents is different; therefore the magnetic circuit of relay should consider not as one, but as three independent quadrature windings, resistive respectively $R_c, R_{кор}$ and $R_я$, and turn number, equal to unity $(w_c = w_{кор} = w_я = 1)$.

If we disregard scattering magnetic flux along the length of magnetic circuit, then these three windings can be replaced with one equivalent quadrature winding whose resistor/resistance to eddy currents will be equal

$$R_ж = \frac{1}{\frac{1}{R_c} + \frac{1}{R_{кор}} + \frac{1}{R_я}}. \qquad (19\text{-}11)$$

The value of resistor/resistance $R_я$ is usually great in comparison with R_c and $R_{кор}$, and therefore value $R_я$ can be disregarded.

$$R_ж \approx \frac{R_c R_{кор}}{R_c + R_{кор}}. \qquad (19\text{-}11a)$$

In this case

Let us substitute into formula (19-11a) instead of $R_c = R_{в1}$ and $R_{кор} = R_{в2}'$ their value from expressions (11-15) and (11-21); set/assuming $\rho_2 = \rho_1$, we obtain:

$$R_{эк} \approx \frac{5{,}78\pi\rho_1\pi^2\rho_2(a^2+b^2)}{l_c l_к ab\left[\frac{5{,}78\pi\rho_1}{l_c}+\frac{\pi^2\rho_2(a^2+b^2)}{l_к ab}\right]} = \frac{5{,}78\pi\rho_1(a^2+b^2)}{1{,}84\, l_к ab + l_c(a^2+b^2)}. \quad (19\text{-}12)$$

Consequently, great voltage on the contacts, which commutate relay with circular core and the housing of rectangular cross section, will be equal to:

$$u_{км} \approx U\left\{1+\frac{5{,}78\pi\rho_1(a^2+b^2)w^2}{[1{,}84\, l_к ab + l_c(a^2+b^2)]R}\right\}. \quad (19\text{-}13)$$

If relay or throttle/choke has the laminated magnetic circuit of rectangular cross section, assembled from a large quantity of plates of sheet steel, then the resistor/resistance of this magnetic circuit to eddy currents will be:

$$R_{эк}' \approx \frac{R_c R_{кор}}{R_c + R_{кор}} = \frac{\pi^2\rho_2(a^2+b^2)n}{ab_1(l_c+l_к)} = \frac{\pi^2\rho_2 ab}{b_1(l_c+l_к)} = \frac{\pi^2\rho_2 a}{b(l_c+l_к)}n^2, \quad (19\text{-}14)$$

where n is a number of plates from which is assembled the magnetic circuit of relay, a and b_1 - width and the thickness of each plate of magnetic circuit, l_c and $l_к$ — the length of core and housings of magnetic circuit and b = nb_1 - thickness of magnetic circuit (packet of plates).

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Great voltage on the contacts, which commutate relay with the laminated core of rectangular cross section,

$$u_{км} \approx U\left[1+\frac{\pi^2\rho_2 abw^2}{b_1(l_c+l_к)R}\right]=U\left[1+\frac{\pi^2\rho_2 an^2w^2}{b(l_c+l_к)R}\right]. \quad (19\text{-}15)$$

In the chapter of eleventh, it is shown, that the resistor/resistance to the eddy currents of the laminated core of square section at equal values ρ_1 = ρ_2 in $n^2/2$ times is more massive (nonlaminated).

For a normal relay of the type RKN $R_к = 19{,}2\cdot 10^{6}$ ohm and $u_{км} \approx 5{,}9\cdot U$, while for analogous choke with the laminated core of square section made of tranformer steel by thickness 0.35 mm $R_к' = 16{,}7\cdot 10^{-3}$ ohm and $u_{км} \approx 4261\cdot U$, i.e., are 722 times more.

However, virtually the value of the greatest voltage on

contacts will be limited by the voltage of the breakdown of air gap between contacts at the moment of their interrupting whose value depends on the speed of interrupting contacts. Usually the value of this voltage does not exceed 1000-1500 V.

Consequently, great voltage on the contacts, which commutate throttle/choke with the laminated core, will be considerably more than on the contacts, which commutate relay with massive (nonlaminated) magnetic circuit at the identical values of the time constant of relay and throttle/choke. Therefore contact tests of relay for service life (number of commutations) with inductive load, must be produced not on throttle/choke with the laminated magnetic circuit, but on the real load which these contacts must switch under normal operating conditions. If for any reasons this is impossible, then instead of the real load it is possible to utilize its equivalent, which has analogous magnetic system on the constant value of time τ and the resistor/resistance of magnetic circuit to eddy currents $R_{м}$.

If relay has quadrature winding, then it is necessary to determine common/general/total equivalent resistance of magnetic circuit and quadrature winding, led to one turn:

$$R_{\text{эк}} = \frac{1}{\frac{1}{R_{\text{ш}}} + \frac{w_{\text{ш}}^2}{R_{\text{к}}}} = \frac{R_{\text{ш}} R_{\text{к}}}{R_{\text{к}} + R_{\text{ш}} w_{\text{к}}^2}. \quad (19\text{-}16)$$

Substituting in equation (19-10a) instead of $R_{\text{ш}}$ value $R_{\text{эк}}$ from last/latter expression, we obtain for the greatest voltage on the contacts, which commutate relay with quadrature winding, the more exact expression, which considers eddy-current effect:

$$u_{\text{макс}} \approx U\left[1 + \frac{R_{\text{ш}} R_{\text{к}} w^2}{(R_{\text{к}} + R_{\text{ш}} w_{\text{ш}}^2) R}\right] = UB. \quad (19\text{-}17)$$

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For excluding the possibility of the appearance of a short-term pulsed discharge between contacts, it is necessary, in order to

$$UB \leqslant U_{\text{пр}},$$

whence

$$B \leqslant \frac{U_{\text{пр}}}{U}. \quad (19\text{-}18)$$

If the breakdown voltage between contacts is equal to 300 V and the voltage of battery is equal to 60 V, then $B \leqslant$

5.

To Fig. 19-4, are given dependence curves of value B for relay of the type RKN from the height/altitude of quadrature winding when $k_{зк} = 0.543$ (wire by diameter 0.1 mm of the brand PEL) and $k_{зк} = 1$ (red copper tube). Their these curves it follows that at quadrature winding by height 0.5 mm value B = 4.14, and at the copper tube of the same height/altitude B = 3.35.

It is necessary to note that quadrature winding, just as the in parallel connected resistor/resistance, slows down the releasing time of relay, moreover the value of this retarding/deceleration/delay in both cases, according to formulas (11-36) and (11.37a), is approximately identical.

d) the connection/inclusion of resistor/resistance in parallel to contacts (Fig. 19-5).

Voltage $U_к$ on contacts will be determined from the equations:

$$U = Ri + L\frac{di}{dt} + ri \quad \textbf{and} \quad U_{\text{к}} = ri.$$

Under the initial conditions i = U/R = I_0 and t = 0, we obtain for $U_{\text{к}}$ the following expression:

$$U_{\text{к}} = ri' = r\left[\frac{U}{R+r} + \frac{U}{R}\left(\frac{R}{R+r}\right)e^{-\frac{R+r}{L}t}\right] =$$
$$= I_2\frac{Rr}{R+r}\left(1 + \frac{r}{R}e^{-\frac{R+r}{L}t}\right). \qquad (19\text{-}19)$$

At the first torque/moment after interrupting with t ≈ 0, we find:

$$U_{\text{к}} \approx U\frac{r}{R}.$$

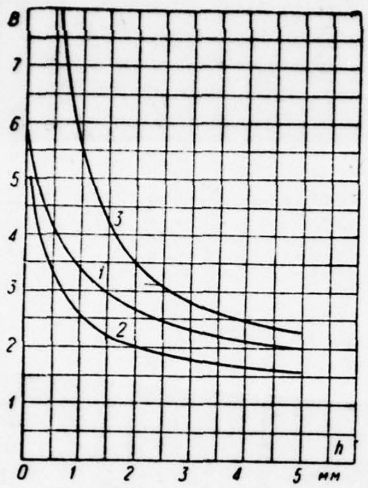

Fig. 19-4. Dependence curve of value B from the height/altitude of quadrature winding for relay of the type RKN with $k_{31} = k_{32}$. $1 - k_{3к} = 0{,}543$; $2 - k_{вк} = 0{,}66$; $3 - k_{вк} = 1$.

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For the limitation of voltage on contacts, the value of resistor/resistance r must be

$$r \leqslant \frac{U_{пр}}{U} R. \qquad (19\text{-}20)$$

On the other hand, for providing the reliable release/tempering of the relay

$$r \geqslant \frac{1 - k_{в}}{k_{в}} k_{отп} R, \qquad (19\text{-}21)$$

where $k_{\text{в}}$ — the relay reset coefficient and

$k_{\text{отп}}$ — the safety factor for release/tempering.

Resetting ratio of electromagnetic relay is usually small. If we accept $k_{\text{в}} = 0{,}1$ and $k_{\text{отп}} = 2$, then during resistor/resistance r < 18R relay will not release.

Therefore for purposes of spark extinguishing, it is profitable to apply nonlinear resistance.

19-3. Nonlinear semiconductor resistor/resistances (varistors).

The nonlinear symmetrical semiconductor resistor/resistances the value of resistor/resistance of which does not depend on direction of flow, are called varistors [19-3, 19-4, 19-5]. (Semiconductor rectifiers are the asymmetric nonlinear resistance).

Symmetrical nonlinear resistance change the value of

their resistor/resistance depending on the voltage of electric field and has comparatively small temperature coefficient.

The nonlinear symmetrical resistor/resistances, which considerably change the value of their resistor/resistance during temperature change, are called thermistors (thermistors).

Thermistors possess the sufficiently large inertness of their parameters, and varistors with small currents are virtually inertia-free.

The resistor/resistance of the varistor, connected in parallel to the winding of relay with nominal supply voltage, is usually sufficiently great, but after interrupting of circuit, it automatically decreases with the increase of voltage on its terminal/grippers, limiting the value of overvoltage on contacts. Therefore varistor consumes in static behavior very small power and considerably lower slows down the operating time of relay than the linear spark-quenching resistor/resistance.

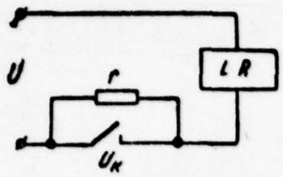

Fig. 19-5. Circuit diagram of resistor/resistance in parallel to contacts.

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Varistors are manufactured from semiconductors on the base of carbide of silicon (carborundum) and ceramic binder.

As fundamental raw material for the production of varistors serves at present technical carbide of silicon (70.045% of Si and 29.955o/o of C).

For providing the stable parameters of the resistor/resistance of grain of carbide of silicon, it is necessary to fasten by binder (clay, ultraporcelain, low-melting glass, water glass, silicone resin or varnish). The material with clay binder, subjected to prolonged firing

with 1200°C, will be called name tyrite; with binder from water glass, long treated with heat at 300°C - vylite and with the ultraporcelain binder, fired by pulse method (method of thermal shock) at 1400-1700°C - letin.

For high-voltage autovalve lightnings-arrestor usually are applied the tyrite, vylite and territe (density 3.2 g/cm³), while for low-voltage varistors - carbide of silicon with ceramic binder, developed under management/manual Prof. V. V. Pasynkov (LETI).

The detailed information about the varistors, produced by industry, is given in the literature [19-3].

For the circuits of automation, the varistors are manufactured usually in the form of wafers with diameter 10 and 15 mm by thickness 1-3 mm. Lead wires are soldered to their lateral sides, copper-plated. Their weight with respect 0.5 and 1.7 g. The photograph of varistors for spark extinguishing is given to Fig. 19-6.

For spark extinguishing in the diagrams of automatic telephone station are manufactured varistors of the type NPS of diameters 15 mm. They are released for the protection

of inductive circuits with operating currents 30, 60, 75, 100, 150 and 200 mA with voltage 60 V. With nominal voltage (60 V) these varistors consume with respect to 0.45; 0.9; 1.125; 1.5; 2.25 and 3.0 mA (tolerance ±20o/o).

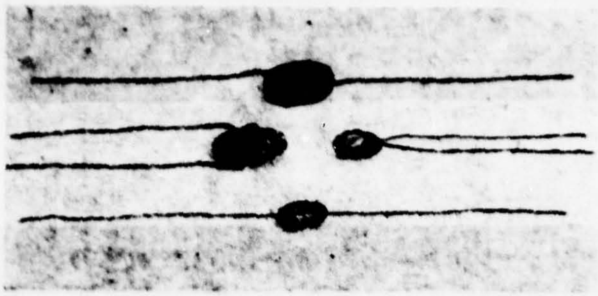

Fig. 19-6. Varistors for spark extinguishing.

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For high voltages and currents, are manufactured shielding vylite resistor/resistances by diameter 75, 100 and 150 mm by thickness 20-50 mm.

To Fig. 19-7, are given dependence curves of the temperature of the overheating of varistors from the amount of power input. From these curves it follows that the temperature of the overheating of varistor by diameter 15 mm at power in 1 W is equal approximately 56°C. The temperature specific resistance of varistors is negative and with a constant value of current equal to 0.002 to 1°C.

To Fig. 19-8 were given curved of the dependences of current on the value of the applied voltage for the different types of varistors and curved of the dependence of the resistor/resistance of varistor No 4 on the current strength. These curves on logarithmic scale are virtually straight lines and, therefore, can be approximated by the following formulas:

$$r = u_0 i^{-\alpha} \text{ and } U = u_0 i^{\beta}. \qquad (19\text{-}22)$$

where u_0 is the constant of varistor whose value is equal to the voltage with current into 1 A;

α is a slope tangent direct/straight lg r = f(lg i) to the axis of abscissas;

β = (1 - α) is an index of the nonlinearity of resistor/resistance, equal to the slope tangent direct/straight lg U = f(lg i).

From expression (19-22) for U we find:

$$i^{\beta} = \frac{U}{u_0} \text{ or } i = \frac{U^{1/\beta}}{u_0^{1/\beta}} = AU^{\gamma},$$

where γ - the percentage distortion of resistor/resistance, equal to $\gamma = 1/\beta$;

A - constant, equal to

According to definition, the index of the nonlinearity of the resistor/resistance

$$\beta = \frac{\lg U_1 - \lg U_2}{\lg i_1 - \lg i_2} = \frac{\lg U_1/U_2}{\lg i_1/i_2}. \qquad (19\text{-}23)$$

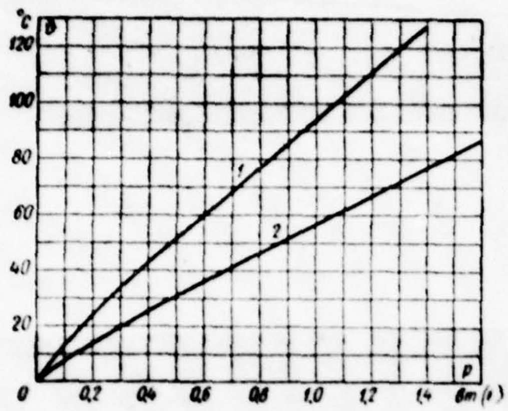

Fig. 19-7. Dependence curves of the temperature of the overheating of varistors from power input. 1 - diameter of varistor 10 mm thickness 2 mm; 2 - diameter of varistor 15 mm thickness 3 mm.

Key: (1). W.

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The value of coefficient u_0 depends on size/dimensions, the composition of materials and technology of the production of varistor.

For the varistors of just one composition, prepared from uniform material on one and the same technology, value

$$u_0 \approx u_{01} \frac{h}{S^{\beta}}, \qquad (19\text{-}24)$$

where u_{01} is the specific value of the constant of varistor, which depends on material and numerically equal to voltage on specimen/sample by size/dimension 1 x 1 x 1 cm (1 cm^3) with current through it into 1 a, h - the thickness of varistor in cm and S - the area of its cross section in cm^2.

The value of the index of nonlinearity β is determined only by technology of production and is found usually within limits from 0.17 to 0.67, while the value of percentage distortion γ, correspondingly, within limits from 1.5 to 6.

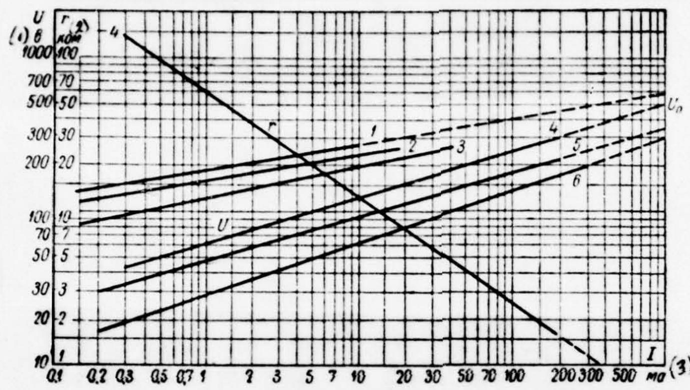

Fig. 19-8. Characteristics of varistors for spark extinguishing. 1, 2, 3 - diameter of varistors 10 mm, thickness 1 mm, β = 0.16-0.21; 4, 5 - diameter of varistors 15 mm, thickness 2 mm, β = 0.3-0.28; 6 - diameter of varistor 15 mm, thickness 3 mm, β = 0.34.

Key: (1). V. (2). kiloohm. (3). mA.

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19-4. Spark-quenching ducts with linear resistor/resistances [19-6].

a) the connection/inclusion of varistor in parallel to winding (Fig. 19-9).

Upon the connection/inclusion of varistor in parallel to the winding of relay great voltage on contacts $U_{\text{км}}$ during their interrupting must be less than the voltage of the breakdown $U_{\text{пр}}$ of the minimum air gap between the contacts:

$$U_{\text{км}} = u_0 I^\beta + U \leqslant U_{\text{пр}}, \qquad (19\text{-}25)$$

where I is conservative value of circuital current of the winding of relay.

Voltage on varistor at the first torque/moment after interrupting of contacts with i = I will be equal to:

$$U_1 = U_{\text{км}} - U = U_{\text{пр}} - U.$$

The value of the resistor/resistance of varistor at current spike I must be:

$$r_1 \leqslant \frac{U_{\text{км}} - U}{I} = \frac{U_{\text{пр}} - U}{U} R.$$

During the steady-state conditions/mode in circuit, the value of the current, passing through varistor i_2 and its resistor/resistance r_2, is determined by the applied voltage and coefficients u_0 and β:

$$i_2^{\beta} = \frac{U}{u_0} \quad \textbf{and} \quad r_2 = u_0 i_2^{\beta - 1}.$$

If is assigned the power $P_в$, consumed by varistor during the steady-state conditions/mode, then

$$i_2 = \frac{P_в}{U} \quad and \quad r_2 = \frac{U^2}{P_в}.$$

The amount of power, consumed by varistor, usually does not exceed 1.5o/o of power, by the expendable winding.

Substituting in expression (19-23) of values U_1 and i_1, which correspond to the torque/moment of interrupting contacts U_2 and i_2 for the steady-state conditions/mode, we will obtain computed value:

$$\beta = \frac{\lg \frac{U_{пр} - U}{U}}{\lg \frac{U^2}{RP_в}} = \frac{\lg \left(\frac{U_{пр}}{U} - 1\right)}{\lg \frac{P}{P_в}}, \qquad (19\text{-}23a)$$

where P - the power, consumed by the winding of relay.

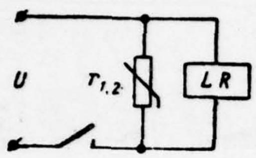

Fig. 19-9.

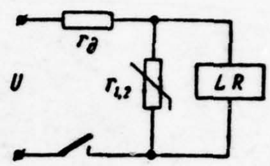

Fig. 19-10.

Fig. 19-9. Circuit diagram of varistor in parallel to winding.

Fig. 19-10. Circuit diagram of varistor in parallel to winding during supplementary resistor/resistance in feed circuit.

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On the other hand, at $i_1 = 1$ a value $U_1 = u_0$ and

$$\beta = \frac{\lg \frac{u_0}{U_1}}{\lg \frac{1}{I}} = \frac{\lg \frac{u_0}{U_{\text{пр}} - U}}{\lg \frac{R}{U}},$$

whence

$$\lg u_0 - \lg (U_{\text{пр}} - U) = \beta \lg \frac{R}{U}$$

or computed value of value u_0 will be equal to:

$$u_0 = (U_{\text{пр}} - U)\left(\frac{R}{U}\right)^{\beta} = \frac{U_{\text{пр}} - U}{I^{\beta}}. \qquad (19\text{-}26)$$

If consecutively in relay circuit included supplementary resistor/resistance $r_{\text{д}}$ (Fig. 19-10), then

$$U_{\text{нм}} = U\left(1 + \frac{r_{\text{э}}}{R + r_{\text{д}}}\right) + u_0 I^{\beta} \leqslant U_{\text{пр}}, \qquad (19\text{-}27)$$

where

$$r_{\text{э}} = u_0 i_{\text{э}}^{\beta - 1}.$$

Computed values of coefficients β and u_0 in this case will be:

$$\beta = \frac{\lg\left[\frac{U_{\text{пр}}}{U} - \left(1 + \frac{r_{\text{э}}}{R + r_{\text{д}}}\right)\right]}{\lg \frac{P}{P_{\text{н}}}}$$

and

$$u_0 = \left[U_{\text{пр}} - U\left(1 + \frac{r_{\text{э}}}{R + r_{\text{д}}}\right)\right]\left(\frac{U}{R}\right)^{-\beta}. \qquad (19\text{-}28)$$

b) the connection/inclusion of varistor in parallel to contacts (Fig. 19-11).

$$U_{\text{км}} = u_0 I^{\beta} \leqslant U_{\text{пр}}. \qquad (19\text{-}29)$$

Great voltage on contacts upon the connection/inclusion of varistor in parallel to the contacts

Computed values of coefficients β and u_0 in this case

$$\beta = \frac{\lg U_{\text{пр}}/U}{\lg P_{\text{в}}/P_{\text{в1}}}$$

and

$$u_0 = U_{\text{пр}} \left(\frac{R}{U}\right)^{\beta} = \frac{U_{\text{пр}}}{I^{\beta}}. \qquad (19\text{-}30)$$

where $P_{\text{в1}}$ — the power, consumed by varistor and winding with dead contacts.

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c) the connection/inclusicn of rectifier in parallel to winding (Fig. 19-12).

Rectifiers are included usually in parallel to the winding in such a way that it is normal as a result of the high value of back resistance the operating current, passing through rectifier, it would be very small. During interrupting of the contacts of emf of self-induction, it is closed through the rectifier in the forward direction, which has small resistor/resistance r_n. Consecutively with rectifier is included resistor/resistance r_i for a decrease in the length of delay of the releasing time of relay and adjustment of ceiling voltage on contacts.

Great voltage on contacts will be:

$$U_{\text{км}} = U\left(1 + \frac{r_n + r_i}{R}\right) \leqslant U_{\text{пр}},$$

whence

$$r_n + r_i \leqslant \left(\frac{U_{\text{км}}}{U} - 1\right) R. \quad (19\text{-}31)$$

If consecutively with the winding of relay included supplementary resistor/resistance $r_д$ (Fig. 19-13), then

$$U_{\text{км}} = U\left(1 + \frac{r_n + r_i}{r_д + R}\right)$$

and

$$r_n + r_i \leqslant \left(\frac{U_{\text{км}}}{U} - 1\right)(r_д + R). \quad (19\text{-}31a)$$

If rectifiers are utilized for an arc extinction, then great voltage on contacts must not exceed the voltage of arc formation.

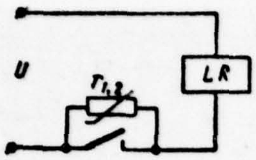

Fig. 19-11.

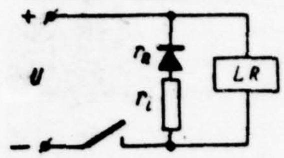

Fig. 19-12.

Fig. 19-11. Circuit diagram of varistor in parallel to contacts.

Fig. 19-12. Circuit for switching in rectifier in parallel to winding.

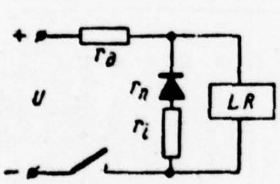

Fig. 19-13. Circuit diagram of rectifier in parallel to winding during supplementary resistor/resistance in feed circuit.

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Effective current, passing through the rectifier,

$$I_э = \sqrt{\frac{1}{T}\int_0^t i^2 dt} = \sqrt{\frac{1}{T}\int_0^t \left(\frac{U}{R}e^{-\frac{t}{\tau}}\right)^2 dt} = \frac{U}{R}\sqrt{\frac{L}{2T(R+r_в+r_д)}}. \tag{19-32}$$

where L is inductance of the winding of relay, τ - the time constant of the circuit of arc extinguishing and T - time between two consecutive interruptings of contacts.

Therefore the rated current to which is designed the rectifier $I_н$, must be not less than value $I_э$.

If time T is more than 500 τ, then value $I_э$ will be less than one thirtieth part of the coil current of relay (U/30R).

19-5. Spark-quenching ducts with resistor/resistance and capacitance/capacity.

Upon the connection/inclusion of resistor/resistance and

capacitor in parallel to contacts (Fig. 19-14) the voltage $U_{\text{к}}$ on contacts is determined as a result of the solution to the differential equations:

$$U = i(R+r) + L\frac{di}{dt} + \frac{1}{C_{\text{к}}}\int i\,dt$$

and

$$U_{\text{к}} = ir + \frac{1}{C_{\text{к}}}\int i\,dt.$$

Solving these equations, we find:

$$U_{\text{к}} = U\left\{1 + e^{-bt}\left[\left(\frac{r}{R} - 1\right)\operatorname{ch} kt + \frac{1}{kR}\left(\frac{1}{C_{\text{к}}} - \frac{R^2 + r^2}{2L}\right)\operatorname{sh} kt\right]\right\}, \quad (19\text{-}33)$$

where

$$b = \frac{R+r}{2L} \quad \text{and} \quad k = \sqrt{b^2 - \frac{1}{LC_{\text{к}}}}.$$

a) aperiodic process $\left(b^2 > \frac{1}{LC_{\text{к}}}\right)$

If k is real value, then in circuit passes aperiodic process. In this case the voltage has maximum value at the

first torque/moment after interrupting of contacts.

For the exception/elimination of the formation/education of spark discharge the value of the resistor/resistance

$$r \leqslant \frac{U_{up}}{U} R. \qquad (19\text{-}34)$$

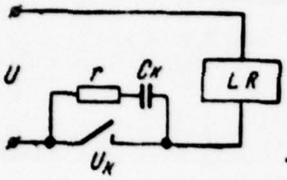

Fig. 19-14. Circuit diagram of resistor/resistance and capacitance/capacity in parallel to contacts.

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During the critical aperiodic process

$$b^2 = \frac{1}{LC_{\text{к}}} = \frac{(R+r)^2}{4L^2},$$

whence

$$C_{\text{к}} = \frac{4L}{(R+r)^2}.$$

Substituting in last/latter expression for r its value from equation (19-34), we obtain:

$$C_{\text{к}} = \frac{4L}{\left(R + \frac{U_{\text{пр}}R}{U}\right)^2} = \frac{4LU^2}{R^2(U_{\text{пр}} + U)^2}. \qquad (19\text{-}35)$$

b) oscillating process $\left(b^2<\frac{1}{LC_\kappa}\right)$

If k is the imaginary value, then in circuit occurs oscillating process and voltage on contacts will be determined by the following expression:

$$U_\kappa = U\left\{1+e^{-bt}\left[\left(\frac{r}{R}-1\right)\cos\omega t+\frac{1}{\omega R}\left(\frac{1}{C_\kappa}-\frac{R^2+r^2}{2L}\right)\sin\omega t\right]\right\}, \tag{19-33a}$$

where

$$\omega=\sqrt{\frac{1}{LC_\kappa}-b^2}.$$

For determining the greatest value of voltage on contacts (value of the first maximum) from expression

(19-33a) it is necessary to preliminarily find the time $t_м$, through which the stress level will be achieved maximum.

This time we find from condition $\frac{dU_к}{dt}=0$; we have:

$$t_м = \frac{1}{\omega}\operatorname{arctg}\frac{y}{x}, \qquad (19\text{-}36)$$

where

$$x = \omega\left(\frac{r}{R}-1\right)+\frac{b}{\omega R}\left(\frac{1}{C_к}-\frac{R^2+r^2}{2L}\right)$$

and

$$y = -b\left(\frac{r}{R}-1\right)+\frac{1}{R}\left(\frac{1}{C_к}-\frac{R^2+r^2}{2L}\right).$$

(If x > 0, then the first will be maximum, and if x < 0, then the first will be minimum).

In the case when r = R, expression for $U_к$ will take the following form:

$$U_к = U\left\{1+e^{-\frac{r}{L}t}\left[\frac{1}{\omega r}\left(\frac{1}{C_к}-\frac{r^2}{L}\right)\right]\sin\omega t\right\}. \qquad (19\text{-}37)$$

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From this expression it follows that for the exception/elimination of boosting on contacts it is necessary, in order to capacitance of the capacitor

$$C_{\kappa} = \frac{L}{r^2}. \tag{19-38}$$

Voltage on contacts will be achieved the maximum through time $t_{\text{м}} = \frac{T}{4}$. Formula (19-38) with the small voltages of battery gives the large values of capacitance/capacity; therefore usually is allow/assumed boosting on contacts of up to U_{np}. For rise time of voltage on contacts of up to maximum value, the distance between contacts increases, since after interrupting contacts continue to diverge from the definite speed. Therefore for the onset of the short-term pulsed discharge among contacts, usually is required voltage more than 300 V.

c) the identification of the parameters of the spark-quenching duct at oscillating process.

For facilitation and accelerating the selection of the capacitance/capacity of condenser/capacitor C_{κ} and of resistor/resistance r of the spark-quenching duct during oscillating process to Figs. 19-15 and 19-16, are given

auxiliary curves.

These curves are:

1) the dependence of values m from x at the different values of n - ratio of limiting stress on contacts $U_{макс}$ to supply voltage U and

2) the dependence of the relative time of the onset of the maximum of voltage θ from value x at different values of m [19-2].

Values m, x, n and θ designate:

$$m = \frac{C_к R^2}{L},\ x = \frac{r}{R},\ n = \frac{U_{макс}}{U} \text{ and } \theta = \frac{R}{L} t_м. \qquad (19\text{-}39)$$

The curves Fig. 19-15 have clearly expressed minimums, which correspond to the minimum value of capacitance/capacity at optimum values $x_{опт}$. The optimum value of value $x_{опт}$ is equal to:

$$x_{опт} = \frac{2}{3} n. \qquad (19\text{-}40)$$

If is known curve to the dependence of the distance between contacts during their interrupting from time, then

parameter determination of spark-extinguishing duct with the aid of the auxiliary curves Figs. 19-15 and 19-16 is conducted by the method successive conducting of.

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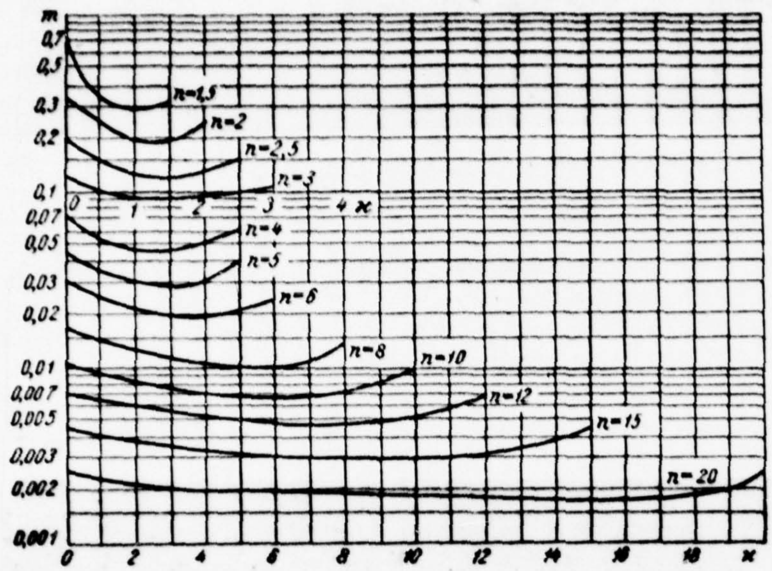

Fig. 19-15. Curved of the dependences of coefficient m on coefficients ϰ and n.

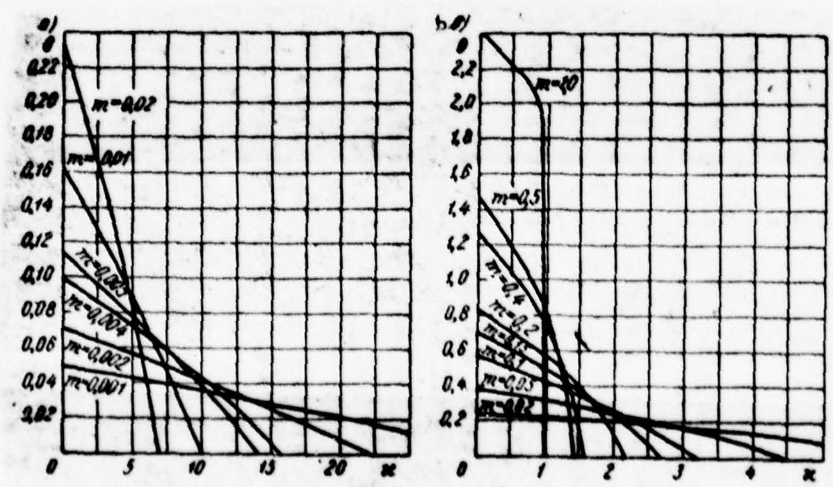

Fig. 19-16.

Fig. 19-16. Curved of the dependences of relative time θ on coefficients $\varkappa$ and m.

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We are assigned first by voltage $U_{макс} = U'_{м}$ and we determine value n. With the aid of formula (19-40) we calculate a value $\varkappa$, through the curves Fig. 19-15 we find value m and then on the curves Fig. 19-16 we obtain value θ. Knowing value θ, we find from formula (19-39) the time $t_{м}$, through which the voltage on contacts reaches maximum. On dependence curve of the distance between contacts during their interrupting from time, we find air-gap clearance between the contacts through time $t_{м}$ and through the curves Fig. 18-11 take the appropriate value of breakdown voltage $U_{пр}$.

If breakdown voltage $U_{пр}$ is more than $U'_{м}$, then we are assigned by intermediate quantity $U'_{м} < U_{макс} < U_{пр}$ and repeat calculation, while value $U_{пр}$ will be more than $U_{макс}$ on 10-20 V.

The parameters of the spark-quenching duct we find with

the aid of the following formulas:

$$C_{\text{к}} = m\frac{L}{R^2} \quad \text{and} \quad r_{\text{опт}} = \varkappa_{\text{опт}} R. \qquad (19\text{-}41)$$

On the initial section of dependence curves of the distance between contacts during their interrupting from time, it is possible to accept the velocity of constant; then

$$\Delta_{\text{к}} = vt + l_{\text{м}}. \qquad (19\text{-}42)$$

The small value of the velocity of the disagreement of the circuit closing contacts of normal relays of the type RPN is approximately equal to 0.013 m/s, and which break - 0.036 m/s.

If the law of the motion of the contacts of relay during their interrupting is unknown, then the parameters of spark-extinguishing duct (in the case of oscillating process) can be tentatively determined with the aid of the curves Fig. 19-15, assuming that the contacts diverge slowly and through time $t_{\text{м}}$ the distance between contacts is equal to the length of bridge $l_{\text{м}}$. In this case value $n = \frac{U_{\text{пр}}}{U}$, and calculated capacitance of capacitor will be more than in the first case.

To Fig. 19-17, are given the curves of the dependences of medium altitude of outgrowths on the contacts of relay of the type RPN on the value of commuted current at the different methods of spark extinguishing and voltage 60 V, constructed according to the results of investigations T. K. Shtremberg.

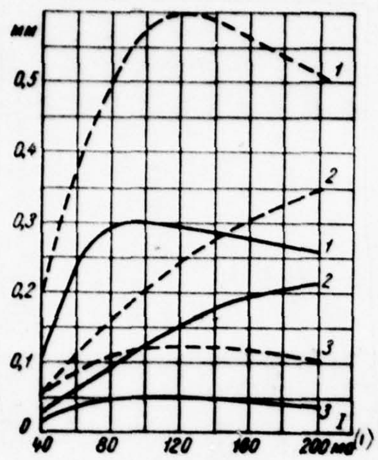

Fig. 19-17. Curved of the dependences of the height/altitude of outgrowths on the contacts of relay of the type RPN on the current strength at the different methods of spark extinguishing. 1 - without spark extinguishing ($3 \cdot 10^6$ cycles); 2 - spark extinguishing with the aid of varistor ($20 \cdot 10^6$ cycles); 3 - spark extinguishing with the aid of duct RC ($20 \cdot 10^6$ cycles). Solid lines is medium altitude of outgrowths; broken - the greatest height/altitude of outgrowths.

Key: (1). mA.

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The value of the diameter of craters and bases of outgrowths on contacts does not in practice depend on current (within limits from 40 to 200 mA) and varies from 0.6 to 1.3 mm. By dotted line are shown the curves of the greatest values of the height/altitude of outgrowths on contacts. The load of contacts inductive - the winding of relay of the type RPN (time constant 0.015 s). From these curves it follows that the spark extinguishing with the aid of varistor considerably decreases the wear of contacts.

In load 80 mA and the absence of spark extinguishing, medium altitude of outgrowths on contacts after $3 \cdot 10^6$ functions is equal to 0.3 mm (maximum - 0.5 mm), but the diameter of crater and outgrowths 0.6-1.3 mm. During the use of a varistor as spark extinguisher, medium altitude of outgrowth (with the same load) after $20 \cdot 10^6$ functions does not exceed 0.09 mm, but the diameter of crater is within the limits from 0.8 to 1.1 mm.

Spark extinguishing with the aid of duct $RC_к$ with the commuted currents of more than 60 mA gives the best effect, than varistor - the lower altitude of outgrowths

and the smaller diameter of crater (0.6-0.8 mm).

Due to the complexity of the phenomena, which occur during closing/shorting and interrupting of contacts, a precise method of the calculation of the optimum parameters of the spark-quenching ducts is not still developed. Therefore the parameters of the spark-quenching ducts, obtained by calculation, must be refined experimentally (testing for service life).

Erosion of contacts is determined by the resultant action of the arc of interrupting and spark, the which give transfer on the anode, and also liquid bridges and the short arcs, which give the transfer in opposite direction from the anode to cathode.

The size/dimensions of erosion depend on the values of current, voltage, inductance, and the capacitance/capacity of circuit, material of contacts, their surface condition, the velocity of closing/shorting and interrupting, bouncing of contacts and environmental conditions.

The capacitance/capacity, connected in parallel to contacts, decreases the erosion during interrupting of

contacts and increases erosion during closing/shorting.

Changing capacitance values and resistor/resistance in the circuit of the spark-quenching duct, it is possible to find the conditions/mode during which the transfer of the metal of contacts to both sides will be approximately identical. In this case the wear of contacts will have least value.

In the absence of spark extinguishing, the amplitude of overvoltage on contacts depends on the self-capacitance of winding, connected in the circuit of contacts.

The self-capacitance of winding can be considerably increased artificially.

For this, the winding is coiled simultaneously by two parallel wires (into two filaments) and consists of two identical windings, moreover end/lead of one of them (first winding) is connected with the beginning of another (second winding).

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The self-capacitance of the winding of relay of the type RPN, which is of two series-connected windings on 4500 turns of the wire of the brand PEL diameter 0.13 mm (r = 2 x 250 ohm) is within the limits 0.002-0.005 μF. After the saturation of this winding with varnish No 447 the self-capacitance of winding increases to 0.005-0.008 μF.

19-6. Arc-arresting equipment/devices.

The contacts, intended for the disconnection/cutoff of high currents, are supplied with the arc-arresting equipment/devices in the form of blowout chambers, horns and the magnetic blow-out.

The magnetic blow-out consists of displacement with the aid of the magnetic field of the arc, which appears between contacts and which is "movable conductor with current".

The forces, which operate on arc, must be directed so that the arc moves upward and simultaneously it is dilate/extended into length.

Magnetic field is created with the aid of the arc-arresting coils, included consecutively or in parallel with the controlled circuit.

The location of the contact plane usually is accepted vertical, the end/leads of the contacts dilute in the form of horns.

The heated gas in the space of arc rises upward, its length rapidly increases, which facilitates arc extinction.

The contacts, which disrupt high currents, are placed in the arc-suppression camera/chambers, manufactured from a cement-asbestos or other analogous materials. The arc-suppression camera/chambers insulate arc from adjacent contacts and increase the speed of arc extinctions. The latter is reached with the aid of vertical slots, which connect the internal cavity of the camera/chamber with external space. During the formation/education of arc, appear the intense airflow, which blow out the arc through slots. In this case, the walls of slot cool arc, contributing to its deionization.

Sometimes in the camera/chamber are arranged longitudinal or transverse iron (copperplated) partition/baffles (the so-called de-ion gratings). In this case arc, being involve/tightened in slot, it is divided into a series of the separate series-connected arcs which rapidly go out due to an increase in the cathode drop in arc [1-2].

19-7. Examples.

1. Let us determine parameters of varistor which must be include/connected in parallel to magnet winding as spark extinguisher.

Voltage of battery 60 V, winding impedance of electromagnet 750 ohm, the inductance of the winding 10.8 H, nominal circuital current of winding 0.08 A.

The greatest permissible value of overvoltage on contacts we take equal to 280 V. Consequently, great voltage on varistor at the moment of interrupting contacts

must not exceed

$$U_1 = 280 - 60 = 220 \text{ V}.$$

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Power, consumed by magnet winding,

$$P = 0{,}08^2 \cdot 750 = 4{,}8 \text{ W}.$$

The power, consumed by varistor with nominal voltage, we take equal to 1.5o/o of the power of the winding:

$$P_в = 0{,}0015 \cdot 4{,}8 = 0{,}072 \text{ W}.$$

Value β, according to formula (19-23a), is equal to:

$$\beta = \frac{\lg\left(\frac{280}{60} - 1\right)}{\lg 4{,}8/0{,}072} \approx 0{,}3.$$

The constant of varistor we find with the aid of (19-26):

$$u_0 = \frac{280 - 60}{0{,}08^{0{,}3}} = 470 \text{ V}.$$

From Fig. 19-8, we find that with current 0.08 A the

voltage on varistors 1, 2, and 3 will considerably exceed 220 V, and on varistor 4 - U = 230 V.

Most adequate/approaching for our electromagnet will be varistor 4, which has β = 0.3 and u_0 = 490 V, since varistors 5 and 6 consume large power with nominal voltage (60 V).

The resistor/resistance of varistor 4 at the moment of interrupting contacts (with I = 0.08 A) is equal to 2900 ohm, and during the steady-state conditions/mode (with U = 60 V) - 60000 ohm, i.e., are 20.7 times, more (I_2 = 0.95 mA).

Therefore the effect of varistor on the releasing time of electromagnet is considerably less than spark extinguisher with linear resistor/resistance.

Releasing time of electromagnet without spark extinguisher 10.7 ms, with varistor 14 ms and with linear resistor/resistance (2750 ohm) as spark extinguisher 41 ms.

2. Let us determine parameters of spark-extinguishing duct, connected in parallel to contacts, which commutate

circuit of winding of relay.

Winding impedance of relay 500 ohm, inductance 2.5 H, the voltage of battery 60 V, circuital current of the winding 0.12 A.

Material of contacts - silver. Atmospheric pressure 760 mm Hg.

From the curves Fig. 18-5 we find the maximum length of the bridge, which is formed between contacts during interrupting, $l_M = 0{,}36 \cdot 10^{-4}$ cm.

The most probable value of the breakdown voltage between silver contacts with distance $0.36 \cdot 10^{-4}$ cm, according to curved Fig. 18-6, is equal to 160 V.

a) aperiodic process.

According to formulas (19-34) and (19-35) we find:

$$r \leqslant \frac{160}{60} \cdot 500 \leqslant 1330 \text{ ohm}$$

and

$$C_{\kappa}=\frac{4\cdot 2{,}5\cdot 60^{2}}{500^{2}\cdot(160+60)^{2}}=30\cdot 10^{-6}\ \phi=30 \quad \mu F.$$

6) oscillating process.

If the law of the motion of contacts is unknown, then according to (19-39) and (19-40) we obtain:

$$n=\frac{U_{\text{пр}}}{U}=\frac{160}{60}=2{,}67 \quad \text{and} \quad \varkappa_{\text{опт}}=\frac{2}{3}n=\frac{2}{3}2{,}67=1{,}78.$$

end section.

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From the curves of Fig. 19.16, we find the appropriate value of m = 0.12. With the aid of formulas (19.41) we have:

$$C_{\kappa} = m\frac{L}{R^2} = 0{,}12 \cdot \frac{2{,}5}{500^2} = 1{,}25 \cdot 10^{-6}\ \phi = 1{,}25\ \mu F.$$

The law of the motion of contacts is known. The velocity of the disagreement of contacts we set/assume equal to 15 cm/s. In this case we are assigned by n = 5 and find to analogously preceding/previous $\varkappa = 3.33$ and m = 0.029.

From the curves of Fig. 19.17, we obtain the relative time of the onset of maximum θ = 18.

Time t_m we determine from formula (19.39):

$$t_{M} = \frac{\theta L}{R} = \frac{0{,}18 \cdot 2{,}5}{500^2} = 0{,}0009\ s.$$

The distance between the contacts after 0.0009 s,

according to (19.42), will be equal to:

$$\Delta_{к} = 15 \cdot 0{,}0009 + 0{,}000036 = 0{,}00139\ см = 0{,}0139\ мм.$$

From the curves of Fig. 18.11, we find breakdown voltage $U_{пр} = 380$ volts.

In this case of n = 380/60 = 6.3, i.e., that more accepted during calculation (n = 5).

We are assigned by value n = 5.6 and repeat calculation.

We obtain:

$$\varkappa = 3{,}74;\quad m = 0{,}018;\quad \theta = 0{,}118;\quad t_{м} = 0{,}00059\ s;$$
$$\Delta_{к} = 0{,}0093\ мм;\quad U_{пр} = 330\ \text{volts};\quad n = 5.5.$$

The parameters of spark-extinguishing duct we find with the aid of formulas (19.41):

$$C_{к} = 0{,}018\,\frac{2{,}5}{500^{2}} = 0{,}18 \cdot 10^{-6}\ ф = 0{,}18\ \mu F \quad \text{and} \quad r = 3{,}74 \cdot 500 = 1870\ \text{ohm}$$

Thus, in the case of oscillating process capacitance of capacitor is obtained considerably less than in the case of aperiodic process.

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Part Four.

RELAY OF THE INCREASED POWER.

Chapter Twenty

RELAY OF AVERAGE POWER.

20.1. Relays of the direct current of the types REN17 and REN18.

The relay of a direct current of the type REN17 is intended for the commutation a direct and alternating circuital current of average power with voltage to 250 v. The general view of relay is shown in Fig. to 20.1. Relay is designed for operation in mobile units during changes in the ambient temperature from -50 to +50°C, relative humidity to 98o/o (at 20 ±5°C) and vibration with frequency from 20 to 45 Hz during acceleration to 2 g. (Relay

maintain/withstands vibration test at frequency 20 Hz and upon acceleration 4 g).

A relay of the type REN17 is developed by author of an instead of the relay direct current of the type MKU-48 which has the heavy unbalanced armature and it is completely unsuitable for a work in mobile units. Furthermore, a relay of the type REN17 has smaller overall dimensions and weight, than as relay of the type MKU-48.

For the purpose of considerable shortening in the time, necessary for mastery/adoption in production, and also essential decrease in the expenditures on the production of new instrument in the construction of relay of the type REN17 are used (with small changes) the fundamental parts of the relay of types RKN and MKU-48. Housing, core with jaws (coil) and the armature of relay of the type RKN are used with small structural/design changes. The rear jaw of coil has four leading-out plugs instead of five. Insulation of the winding of relay from core is intensified, it consists of five layers of the varnished insulating cloth of brand LSh-1 by thickness 0.1 mm. Winding is saturated with varnish No 447. Inner diameter of the winding 10.1 mm, height 6.4 mm length 59.1 mm.

Contact groups are assembled on two pins, strengthened to the housing of relay.

Contact and supporting springs, steel cover plates and insulating plastic separators are used the same as in relay of the type MKU-48s.

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Magnetic system and all fasteners have the intensive anticorrosive coating (zinc 30 μ chromized).

Effort/force from armature is transmitted to contact springs with the aid of two-way plastic comb/rack (bush). For an increase in the vibration resistance of relay, the armature is held by two flat/plane return springs. Pressure of return springs on armature from 10 to 15 grams.

The contact system of relay consists of two groups and can have from 4 to 12 contact springs. Course of armature 1.5-1.7 mm, the height/altitude of the plug of loosening 0.1 mm. Pressure of contact springs on supporting/reference

10-20 grams. Pressure in contacts 20-25 grams, gaps among contacts are not less than 0.9 mm. Power, consumed during function by the winding of relay, 0.15-0.6 W. With the nominal voltage of relay, consumes 0.5-2 W.

Greatest permissible continous rating 4.5 W (at ϑ = 50°C). The relay reset coefficient 0.15-0.2, at the height/altitude of the plug of loosening 0.5 mm are 0.3-0.4. Great operating voltage of winding and contacts by 250 volts, the maximum current of contact system 5 A.

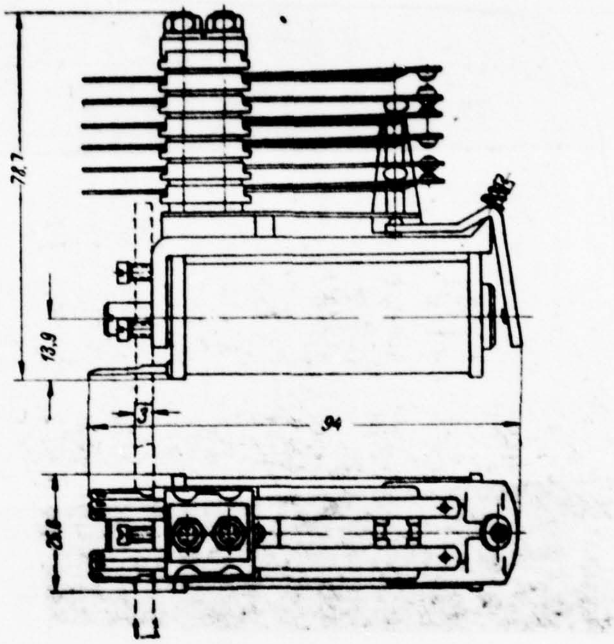

Fig. 20.1. Relays of direct current of type REN17.

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Power, switched by contacts with non-inductive load and direct current, 50 W (0.23 A - 220 volts), alternating current by frequency 50 Hz - to 500 volt-amperes (2.3 A - 220 volts). Service life of the relay of 10^5 cycles.

The testing voltage of insulation of winding 1000 eff. V, of insulation of contact system 1000 volts. The

insulation resistance of relay under normal conditions is more than 500 MΩ, after the stay for 48 h under conditions of increased humidity 98o/o - it is not less than 10 MΩ. Relay is fastened to board by three screw/propellers.

Overall dimensions of relay 25.6 x 78.4 x 94 mm, weight 300 g.

Table 20.1 gives the ampere-turns of function and release/tempering of relay of the type REN17 with different loads. The ampere-turns of function are given with the production certified/rating reserve into 15o/o.

The working safety factor on the current (ampere-turns) of function for a current relay must be not less than 1.3 ($K_I \geqslant 1.3$).

Voltage relays must reliably wear/operate during decrease in the voltage to 85o/o from nominal value $k_H = 0.85$.

For voltage relay, the working safety factor on voltage must be not less than 1.5.

Figures 20.2 gives the curves of the dependences of the time delay of the type REN17 on the safety factor on ampere-turns. Figures 20.3 gives dependence curves of the releasing time of relay of the type REN17 with $K_1 = 1.6$ it is within the limits from 50 to 70 ms, and releasing time varies from 10 to 30 ms.

A relay of the type REN18 differs it is characterized by from REN17 the construction of coil. Coil form of relay of the type REN18 is pressed from plastic, for double wound coils the framework/body has supplementary jaw (partition/baffle) insulating windings from each other.

Table 20.1. Ampere-turns of the function of the relay of types REN17, REN18 and REN19 at the height/altitude of the plug of loosening 0.2 mm.

Контактная нагрузка (1)	Тип (2) РЭН17	Тип (2) РЭН18	Тип (2) РЭН19
2 замыкающих контакта (3)	230	274	—
1 размыкающий контакт (4)	—	212	—
2 размыкающих контакта (5)	219	—	235
2 переключающих контакта (6)	247	285	257
2 переключающих + 2 замыкающих контакта (7)	310	334	320
4 переключающих контакта (6)	328	340	381
4 замыкающих контакта (3)	—	338	—
6 замыкающих контактов (8)	—	380	—

Key: (1). Contact load. (2). Type. (3). circuit closing contacts. (4). the breaking contact. (5). breaking contact. (6). stud switch. (7). the changing over +2 circuit closing contacts. (8). circuit closing contacts.

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A relay of the type REN18 is intended for operation at temperatures from +5 to +40°C, relative humidity to 98o/o at 20°C. Operating voltage of the winding of this relay to 450 volts.

Upon the series connection of two adjacent contact groups of relay of the type REN18, can switch 0.27 a direct current (120 W) or 2 a alternating current (900

volt-amperes) with resistive load and voltage 450 volts. Service life of the contacts of the relay of 10^5 functions. Frequency of functions 1 imp./s.

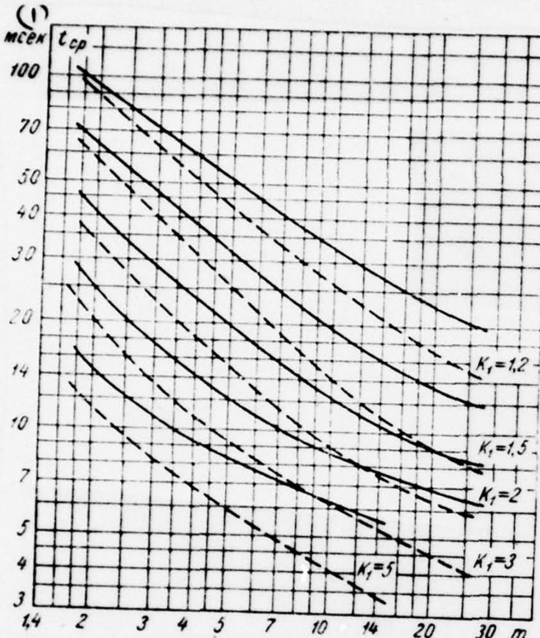

Fig 20.2

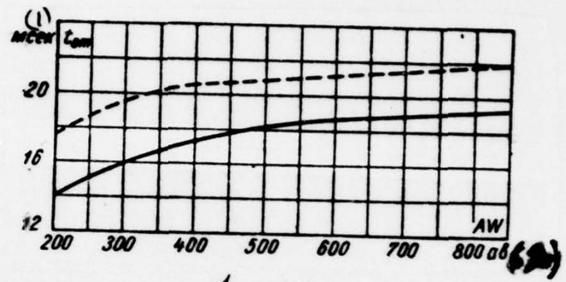

Fig. 20.3.

Fig. 20.2. Curved of time delay of type REN17.

Key: (1). ms.

Fig. 20.3. Curved of releasing time of relay of type REN17.

Key: (1). ms. (2) AV.

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The ampere-turns of the function of a single-winding relay of the type REN18 with different lcads with the certified/rating reserve into 15o/o are given in Table 20.1. If coil form webbed, then the ampere-turns of function from the winding, located on pole, are 97o/o, and from winding, which is located of the base of relay - 130o/o of ampere-turns of the function of normal single-winding relay.

20.2. Relays of alternating current of the type REN20.

The relay of alternating current of the type REN20 is intended for the commutation a direct and alternating circuital current of average power with vcltage to 250 volts. The general view of relay is shown in Fig. 20.4.

Relay is designed for operation in mobile units during changes in the ambient temperature from -50 to +50 °C, relative humidity to 98o/o (at 20±5°C). Relay maintain/withstands vibration test in the range of frequencies from 15 to 45 Hz during acceleration 3 g and

from 40 to 70 Hz during acceleration 2 g, and also testing for impact strength during acceleration 50 g (500 impacts).

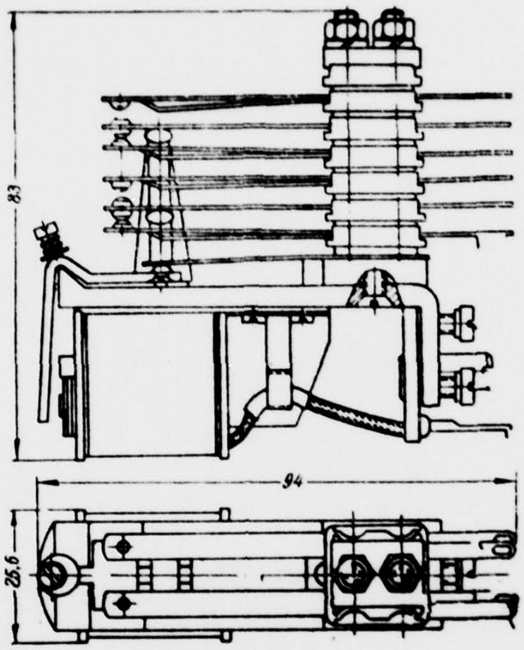

Fig. 20.4. Relays of alternating current REN20.

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The test voltage of insulation of winding and contacts is equal to 1000 eff. V.

A relay of the type REN20 is developed by author of an instead of the relay alternating current of the type MKU-48s, unworkable in mobile units. In the construction of relay of the type REN20, are also used many parts of the

relay of types RKN and MKU-48 for a considerable decrease in the expenditures of time and resources for mastery/adoption of the new type of relay. Housing and the armature of relay of the type RKN are used with small structural/design changes. Core has L-shaped form, it is assembled made of sheet tranformer steel by thickness 0.35 mm, it is tightened by two steel plates with the bent back end/leads and it is attached four by screw/propellers to the internal plane of housing.

¶ Core is 6 x 12 mm, calculated length its 33.2 mm. Free end/lead (pole) is bisected; on the lower part of the pole, is placed the short-circuited shielding winding, which is of three red copper right-angled washers section (1.5-4) x 0.8 mm (thickness 0.8 mm).

The equivalent inner diameter of the winding 12.1 mm, height/altitude its 7.4 mm and length 27 mm. Winding is isolate/insulated from core five by layers of the varnished insulating cloth of brand LShch-1 and it is saturated with varnish No 447.

The contact system of relay has the same construction, as in relay of the type REN17, it consists of two groups

and can have from 4 from 12 contact springs. Course of the armature of relay 1.8 mm. Pressure in the contacts 20-25 g, gaps among contacts are not less than 0.9 mm. The winding of relay is intended for feed by alternating current by frequency 50 Hz.

Power, consumed by winding during the function of relay, 1.6 W (2.6 volt-amperes). With the nominal voltage of relay, consumes 3.2 W (5.5 volt-amperes). Maximum permissible continous rating 5.1 W (8.2 vclt-amperes) (at ϑ = 50°C). Great operating voltage of winding and contacts by 250 volts, the maximum current of contact system 5 A. Power, switched by contacts so on resistive load and direct current 50 W (0.23 A - 220 volts), with alternating current by frequency 50 Hz - to 500 volt-amperes (2.3 A - 220 volts).

Service life of the relay of 10^5 cycles. The testing voltage of insulation of winding and contacts 1000 eff. V. The electrical insulation resistance of relay under normal conditions is more than 100 MΩ with the increased humidity - 10 MΩ.

Overall dimensions of relay 25.6 x 83 x 94 mm, weight 250 g.

For determining the ampere-turns of function Fig. 20.5 gives the electromechanical characteristics of relay of the type REN20 at frequency 50 Hz. With the aid of these curved and mechanical characteristics of contact groups, it is possible to find the ampere-turns of the function of the relay, which has any load.

Table 20.2 gives the starting/launching ampere-turns of function (with the nonpullled armature) for a relay of the type REN20, loaded by some most widely used combinations of contact groups.

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This table is comprised taking into account the production (certified/rating) reserve into 10o/o. The voltage of the function of the relay of alternating current must be not more than 80-85o/o nominal value of operating voltage.

Inductance, active and complete winding impedance of the relay of alternating current, as is known [20.4], they can be expressed by the following formulas:

$$L = K \cdot w^2,\ R = C \cdot w^2 \text{ and } Z = \sqrt{R^2 + (\omega L)^2} = \sqrt{C^2 + (\omega K)^2} \cdot w^2, \quad (20\text{-}1)$$

where K and C - the coefficients whose values depend on construction and the size/dimensions of relay, and also on the parameters of the material of magnetic circuit.

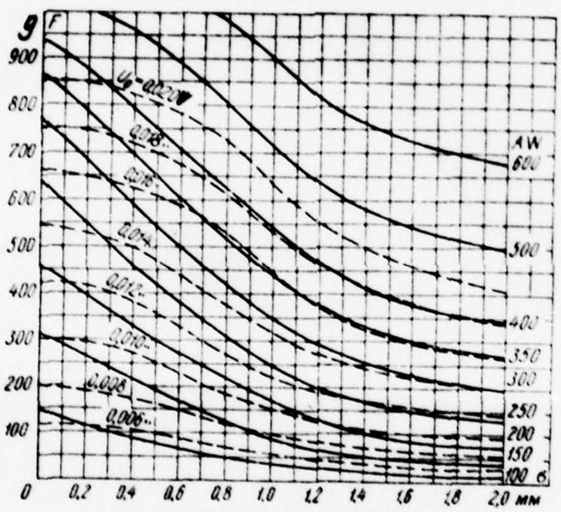

Fig. 20.5. Electromechanical characteristics of relay of type REN20.

Table 20.2. Ampere-turns of the function of relay of the type REN20.

Контактная нагрузка (1)	AW
2 переключающих контакта (2)	294—330
2 переключающих +2 замыкающих контакта (3)	398
4 переключающих контакта (2) . . .	330—397

Key: (1). Contact load. (2). stud switch. (3). the changing over +2 circuit closing contacts.

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The turn number of the winding of the relay of alternating current

$$w = \frac{U}{u_0}, \qquad (20\text{-}2)$$

where u_0 - the stress level, which is necessary to one turn of the winding of relay; u_0 depends on construction and the size/dimensions of relay.

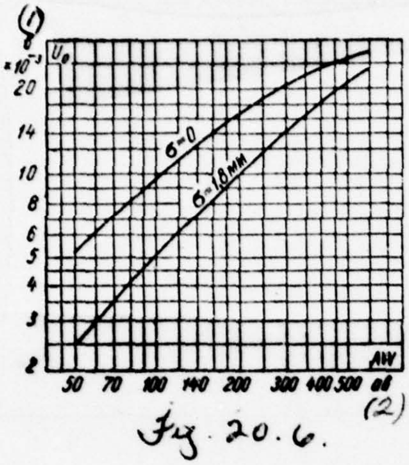
For the assigned type of relay coefficients K, C and

u_0 also of nonoperative ampere-turns and frequency of the feeding alternating current. Coefficient C, furthermore, it depends also on filling of winding space of coil, diameter of wire and thickness of its insulation. Values of coefficients of K, C, and u_0 for each type of relay can be determined experimentally.

The calculation of the electromagnetic relays of alternating current is in more detail presented in the preceding/previous (the second) publication of this book [20.4].

For the calculation of the windings of relay of the type REN20 on Fig. 20.6 and 20.7, are given dependence curves of average values u_0 and of coefficients K and C from ampere-turns at the extreme values of clearance [pulled (σ = 0) and nonpullled (σ = 1.8 mm) the positions of armature].

Angle of displacement between the vectors of current and stresses with the pullled armature is equal approximately 58-60° (cos ϕ = 0.50-0.53).



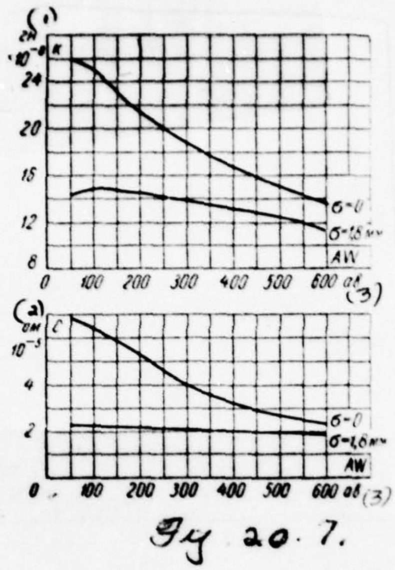


Fig. 20.6. Curved of dependences u_0 on ampere-turns for relay of type REN20.

Key: (1). Volts. (2) AV.

Fig. 20.7. Curved of coefficients K and C for relay of type REN20.

Key: (1). H. (2). ohm. (3) AV.

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The time delay of the type REN20 with nominal voltage is within the limits approximately 9-11 ms, while releasing time 10-12 ms.

Figures 20.8 gives the curves of the dependences of the attracting force of the different types of the relay of alternating current on the amount of the power (volt-ampere), consumed these relays in pullled ($\sigma = 0$) and nonpullled ($\sigma = 2$ mm) the positions of armature (frequency 50 Hz).

From these curves it follows that a relay of the type REN20 consumes smaller power than by the relay of types MKU-48 and REN21. The power, consumed by relay at kick-off torque with the nonpullled armature, is 1.6-1.7 times more the power, consumed by these relays with the pullled armature.

Fundamental these some standard relays are given in Appendix 1.

20.3. Relays of alternating current of the type REN21.

A relay of the type REN21, developed by author, is the modernized relay of the type RKP.

The general view of relay is given in Fig. 20.9. Housing, armature and the contact system of relay of the type RKP are used without changes. To inside of housing, is attached four by screw/propellers steel corner iron with shortened coil. Corner iron is bent made of sheet steel as thickness 3 mm and has in its base four elongated holes, which make it possible to move coil along housing during gap adjustment between the unshielded part of the pole and armature. The armature of relay does not have a plug of loosening. Core is made made of steel of brand EA (or E) by diameter 9 mm, length its 33 mm. Front/forward end of the core (pole) is bisected; on the lower half of pole, is placed the short-circuited shielding winding, which is of four locked red copper semirings (washers) thickness 0.8 mm.

The rear jaw of coil does not have leading-out plugs, the end/leads of the winding are derive/concluded by flexible multiple drive in excelsior tube.

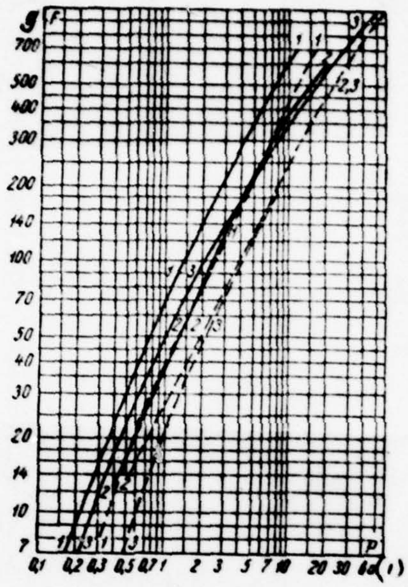

Fig. 20.8. Curved of dependences of attracting force of different types of relay of alternating current on power.

Key: (1). volt-ampere.

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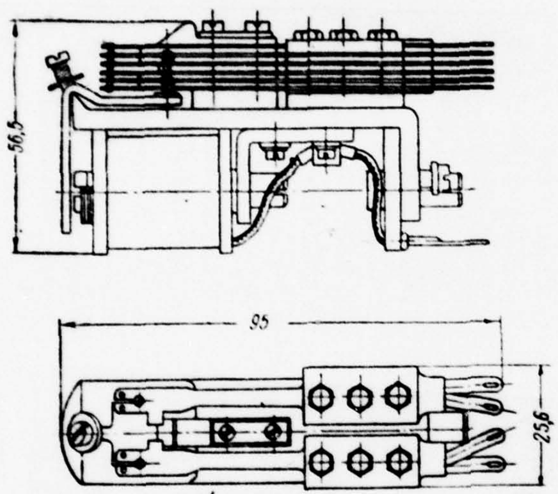

Fig. 20.9

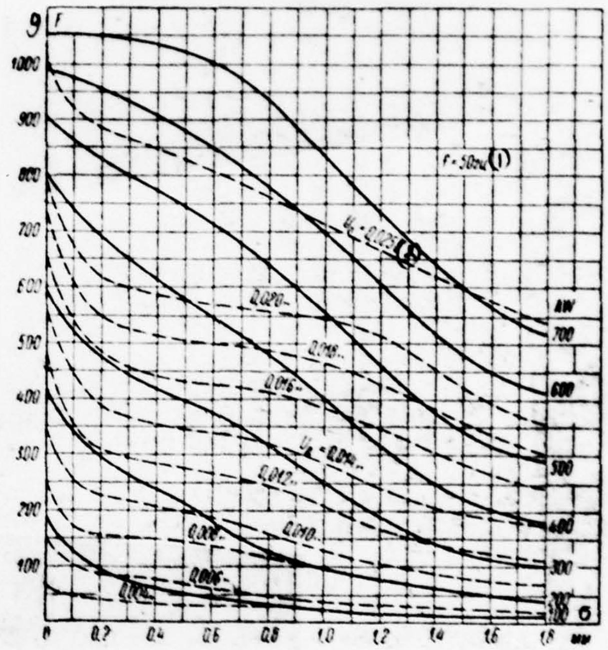

Fig. 20.10.

Fig. 20.9. Relays of alternating current of type REN21.

Fig. 20.10. Electromechanical characteristics of relay of type REN21 at frequency 50 Hz.

Key: (1). Hz. (2). Volts.

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Winding is isolate/insulated from core five by layers of silk varnished insulating cloth and it is saturated with heat-resistant varnish No 447.

Winding space of coil 22.5 x 6.5 mm, the inner diameter of the winding 10 mm.

For using the standard mounting on the back of the housing of relay, is fastened the second rear jaw with two normal leading-out plugs to which the tips of the winding.

The consumption of copper for the winding of relay of the type REN21 is approximately 40 g instead of 96 g on relay of the type RKP. Operating voltage of the winding of relay to 220 volts (testing voltage 1000 volts), contact system - to 60 volts. The load of contacts 0.2a is 60 volts, the service life of relay 1 million functions.

The peak load of relay is 12 contact springs instead of 4-6 springs of relay of the type RKP. The sensitivity of relay of the type REN21 at frequency 50 Hz is approximately 3 times more than relay of the type RKP.

Tables 20.3. Ampere-turns of operation of relay of the type REN21.

Номера контактных групп (1)	f = 50 гц (2)	f = 25 гц (2)	f = 16 гц (2)	Номера контактных групп (1)	f = 50 гц (2)	f = 25 гц (2)	f = 16 гц (2)	σ, мм
1	69—70 100—102	61—75 102—124	73—97 130—160	3+3	110—144 160—201	114—161 178—244	152—318 241—407	0 0,8
2	75—85 110—122	72—81 98—123	72—91 125—155	4+4	100—112 145—163	85—125 137—198	106—174 178—264	0 0,8
3	84—95 120—140	66—94 110—160	87—128 148—220	1+2	99—105 141—145	96—144 154—177	134—160 214—244	0 0,8
4	68—74 100—105	59—69 99—113	70—91 124—152	1+3	109—129 157—152	98—220 158—312	137—225 222—337	0 0,8
6	94—109 136—160	89—117 143—185	112—167 184—251	2+3	100—124 140—175	101—147 163—224	129—233 211—323	0 0,8
12	107—134 154—190	75—152 196—235	205—261 291—350	2+6	105—142 151—198	118—169 187—253	163—316 251—402	0 0,8
41	175—200 250—275	— —	— —	12+12	210—290 285—380	350—290 450—534	436—720 545—850	0 0,8
1+1	100—110 145—160	97—115 152—184	125—173 204—258	12+41	325—450 430—545	— —	— —	0 0,8
2+2	117—119 135—167	91—128 150—196	115—197 193—281					0 0,8

Key: (1). Numbers of contact groups. (2). Hz.

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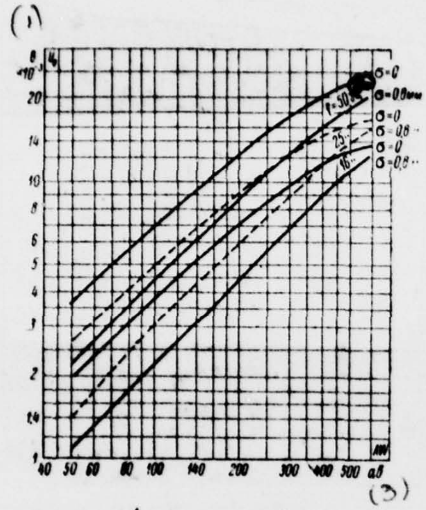

Fig. 20.11

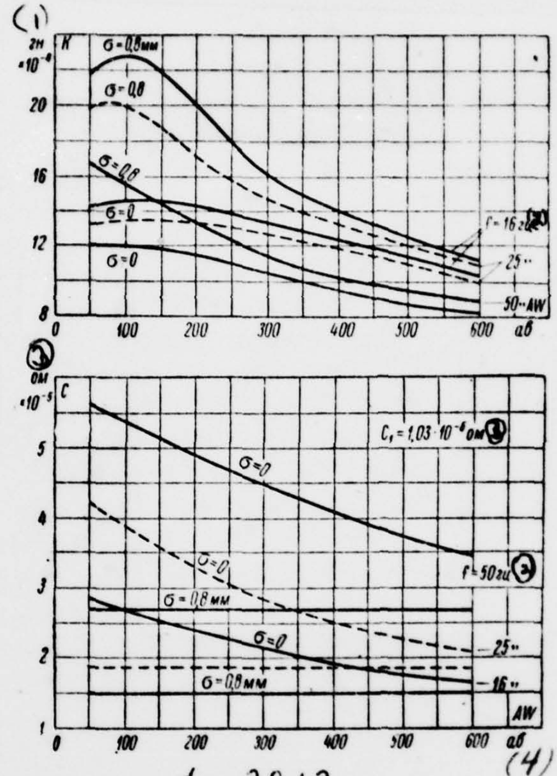

Fig 20.12.

Fig. 20.11. Curved of dependences u_0 on ampere-turns for relay of type REN21.

Key: (1). Volts. (2). Hz. (3). A.V.

Fig. 20.12. Curved of coefficients K and C for relay of type REN21.

Key: (1). H. (2). Hz. (3). ohm (4). AV.

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For the function of relay, loaded by one group for closing/shorting, at frequency 50 Hz it is necessary to 0.34 volt-amperes (0.5 volt-amperes), and at frequency 25 Hz, it is necessary to 0.28 volt-amperes (0.46 volt-amperes).

Figures 20.10 gives the curves of the dependences of the attracting force of relay of the type REN21 on the value of clearance at the different values of ampere-turns and values u_0.

The ampere-turns of the function of relay of the type REN21, loaded any of five fundamental types of contact groups at frequencies 16, 25 and 50 Hz, are given in table 20.3. The curves of the dependences of coefficients u_0, K and C on ampere-turns at different clearances and frequencies 16, 25 and 50 Hz are given in Fig. 20.11 and 20.12. Maximum prolonged continous rating and frequency 50 Hz is equal to 6.6 volt-amperes (ϑ = 50°C), but with

direct current - 3.6 W. Angle of displacement between the vectors of current and stresses 40-42° (cos ϕ = 0.74-0.76).

20.4. Multicontact standardized relay of the type MKU-48.

The multicontact standardized relay of a direct and alternating current of the type MKU-48 (Fig. 20.13) is intended for control of feeding and signal circuits in stationary equipment for automation, telemechanics and communication/connection with voltage to 220 volts direct currents even 380 volts alternating current.

Relays of the type MKU-48 can be operated with ambient temperatures from +10 to +35°C, relative humidity 65 ±15o/o at temperature 20°C and atmospheric pressure 670-780 mm Hg. Relays test for vibration stability at frequencies 15-40 Hz and upon acceleration 3 g, but to the impact strength during acceleration 15 g (2000 impacts).

For tropical operating conditions, it is manufactured with relay of the type MKU-48T which can work at temperatures from -10 to +55°C and relative humidity to 98o/o at temperature of 35°C. Vibration stability of relay 3.5 g at frequencies 10-70 Hz and the impact strength 15g.

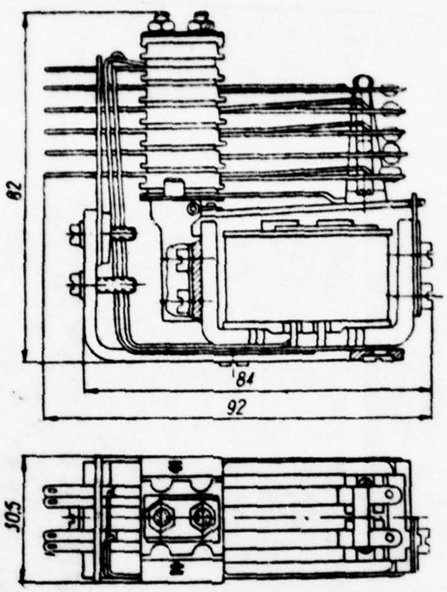

Fig. 20.13. relay of the type MKU-48.

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The weight of relay without cap/hood is not more than 350 g, with base and cap/hood - 550 g.

Magnetic relay circuit consists of the core of v-shaped form and flat/plane armature. The core of relay is bent made of strip steel of brand E by thickness 3.5 mm in such a way that the average part of it is arrange/located perpendicular to two extreme parts, which are the housing of relay.

of relay.

Of the middle part of the core whose width is equal to 22 mm and length 26.5 mm, is arrange/located the coil of relay with framework/body from plastic. The free end/lead of the middle part of the core (pole) is divided on two parts by groove/slot by width 3.6 mm. On the right side of the pole, is placed closed loop from copper sheet by thickness 1.5 mm (section of this turn 5.9 x 1.5 mm). For relay of the type MKU-48 of direct current, closed loop is manufactured from steel and serves as the pole piece for an increase in permeance of clearance, and also for the retention of the coil of relay. Winding space of coil 7 x 21 mm, the equivalent value of the inner diameter of the winding 19.7 mm. The magnetic system of relay by two screws is screwed on to the steel clamp, serving for the attachment of relay to board.

To the left side of the housing by two screw/propellers is attached the base with two contact groups and armature, while to right - a travel limiter of armature.

The contact system of relay consists of two groups,

each group can have from two to eight of contact springs. "motionless" contact springs are made from solid white copper by thickness 0.35 mm, movable springs - made of spring thermalization/heat-treated steel of brand 65G by thickness 0.25 mm. Width of springs 5 mm, working length 41.5 mm.

Contact springs are tightened and isolate/insulated from each other and housing by separators of plastic.

"Motionless" contacts have a diameter 4.2 mm and a height 2 mm, movable - 4 mm and height 1.5 mm. Contacts are made from silver of brand SrM900.

Distance between the contacts 0.9-1.0 mm. The armature of relay is made made of sheet steel by thickness 2 mm, the width of armature 21 mm. The relay of direct current has at armature nonmagnetic antistick strip as thickness 0.2 mm. On top to armature is riveted block (or framework), serving for switching of contact springs.

In calm position the armature is pressed against limiter under the action of recurrent flat spring. The initial pressure of armature, measured of its end/lead (of limiter), is equal to 5-8 g.

limiter), is equal to 5-8 g.

The course of the armature of relay, measured of limiter, is equal to 2 mm (against the middle of core the course of armature it is equal approximately to 1 mm). Pressure in the resting contacts 14-16 g, in the make contacts 24-26 g.

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Operating voltage of winding and contact system to 220 volts. Maximum current of contact system 5 a. The breaking capacity of contacts in direct-current circuit with inductive load (< 2 H) 50 W, in the alternating current circuit of 500 volt-amperes.

Service life of relay 1 million functions.

Maximum permissible continous rating of the relay of alternating current without base and cap/hood of 7.2 volt-amperes (5.6 W) (at ϑ = 50°C). Angle of displacement between the vectors of current and stresses with pulled armature 42-45° (cos ϕ = 0.75-0.71).

A relay of the type MKU-48 is manufactured also with base and cap/hood from plastic (Fig. 20.14).

Cap/hood has from the front an aperture, shielded as glass for observation of work of contacts. On the basis are placed in two series of 10 terminal/grippers for the connection of winding and contact springs. The peak load of relay with base and cap/hood of 8 contact springs. The capacity of the d-c relay with base and cap/hood 2.8 W, without base and cap/hood 3.1 W (at ϑ = 50°C).

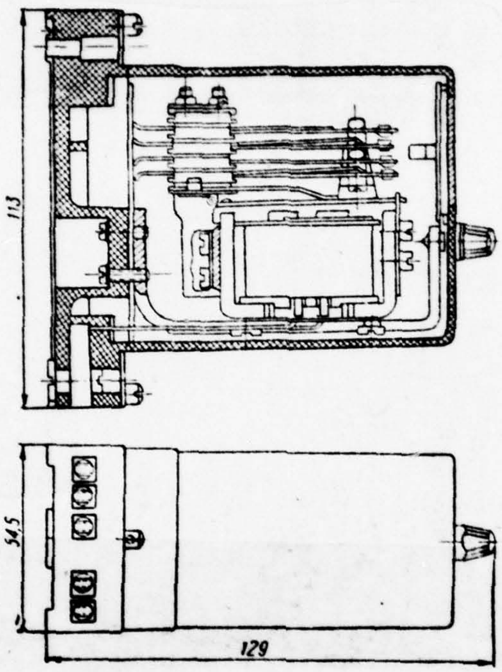

Fig. 20.14. Relays of type MKU-48 with base and cap/hood.

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The relay reset coefficient of direct current with δ_0 = 0.2 mm is approximately equal tc 0.4-0.5, and with δ_0 = 0.5 mm - about 0.6. The relay reset coefficient of alternating current is tentatively equal tc 0.51-0.56.

A relay of the type MKU-48s is intended for operation

at ambient temperature of $\pm 50^{\circ}C$ and relative humidity to 98o/o (at 20 $\pm 5^{\circ}C$). For this purpose the magnetic system of relay and all fasteners have the intensive anticorrosive coating. All contact springs are made from white copper. The peak load of the relay MKU-48s is eight contact springs instead of ten.

For determining the ampere-turns of the function of relay Fig. 20.15 and 20.16 gives the electromechanical characteristics of relay of the type MKU-48 of direct and alternating current.

With the aid of these curved and mechanical characteristics of contact groups, it is possible to find the ampere-turns of the function of the relay, which has any load.

The service life of the contacts of relay of the type MKU-48s is equal to 10^5 functions (at $35^{\circ}C$). Triggering time with nominal voltage is not more than 60 ms.

Table 20.4 gives the ampere-turns of function for the relay of direct current and the starting/launching ampere-turns of function (with the nonpulled armature) for the relay of alternating current of the type MKU-48, loaded by different contact groups.

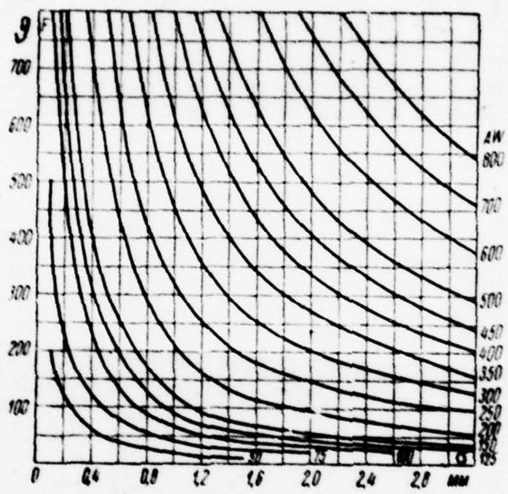

Fig. 20.15. Electromechanical characteristics of relay of type MKU-48.

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The table of ampere-turns is comprised taking into account production reserves. The voltage of the function of the relay of alternating current is within the limits from 0.79 to 0.85, while the voltage of the function of the relay of direct current - within limits from 0.75 to 0.8 nominal values of voltage.

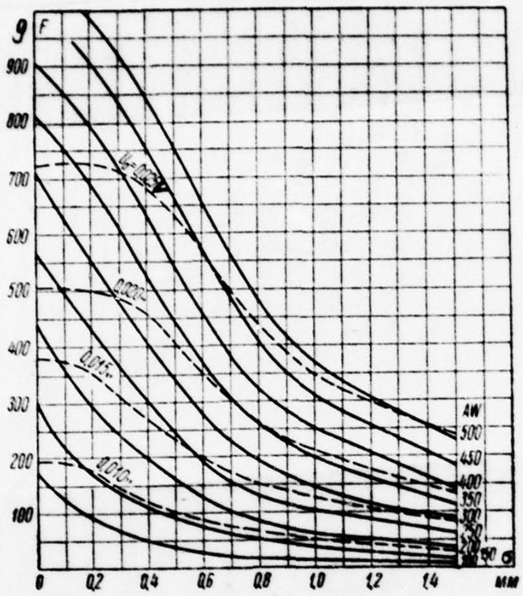

Fig. 20.16. Electromechanical characteristics of relay of alternating current of type MKU-48.

Table 20.4. Ampere-turns of the function of relay of the type MKU-48.

Контактная нагрузка (1)	Постоянный ток (2)	Переменный ток 50 гц (3)
2 замыкающих контакта (4)	130	185
4 замыкающих контакта (4)	180	260
2 размыкающих контакта (5)	187	260
4 размыкающих контакта (5)	230	290
2 переключающих контакта (6)	190	260
2 замыкающих + 2 размыкающих контакта (7)	190	260
2 замыкающих + 2 переключающих контакта (8)	200	275
2 размыкающих + 2 переключающих контакта (9)	230	300

Key: (1). Contact load. (2). Direct current. (3). Alternating current 50 Hz. (4). circuit closing contacts. (5). breaking contact. (6). stud switch. (7). the closing + 2 of breaking contact. (8). the closing + 2 of stud switches. (9). breaking + 2 stud switches. (9). breaking + 2 stud switches.

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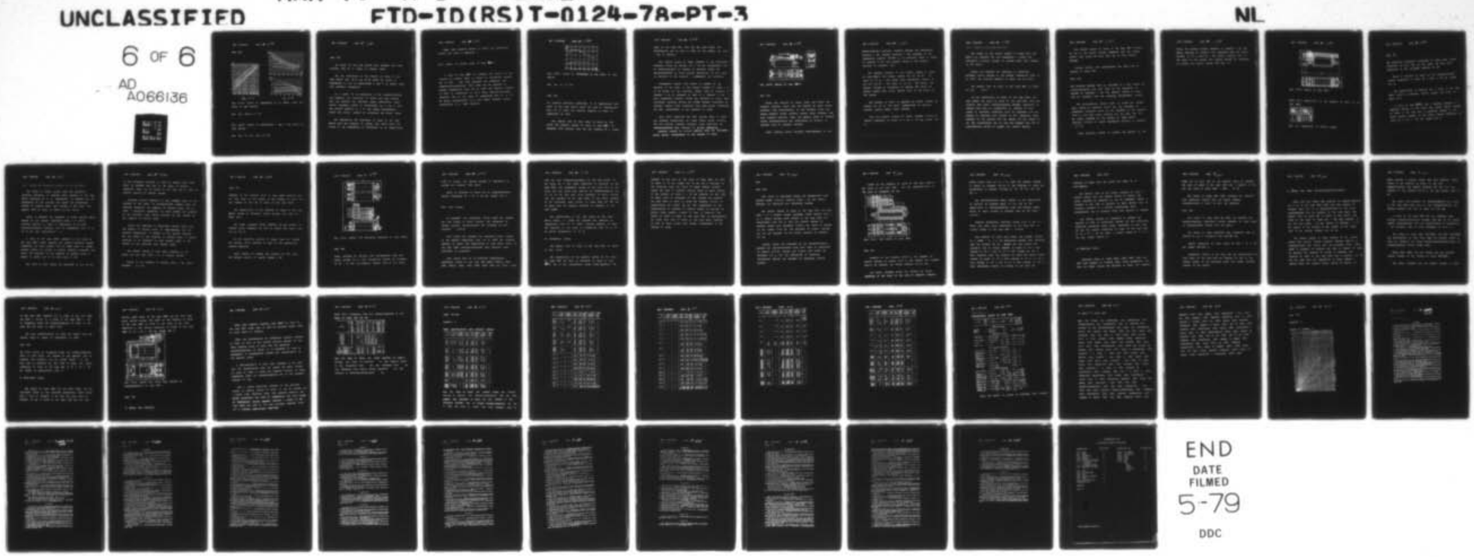

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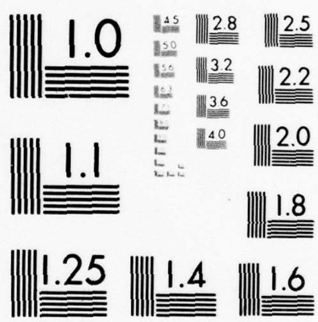

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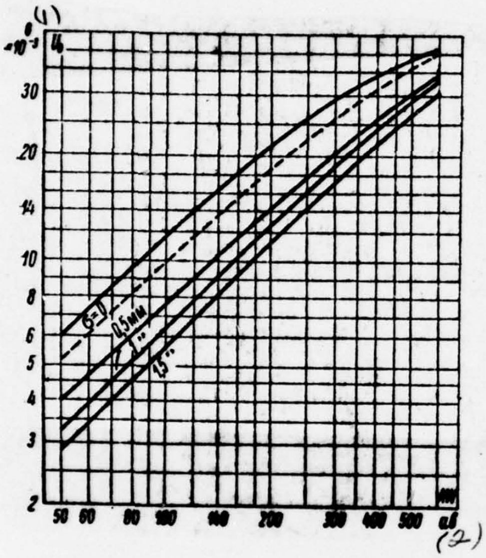

Fig. 20.17.

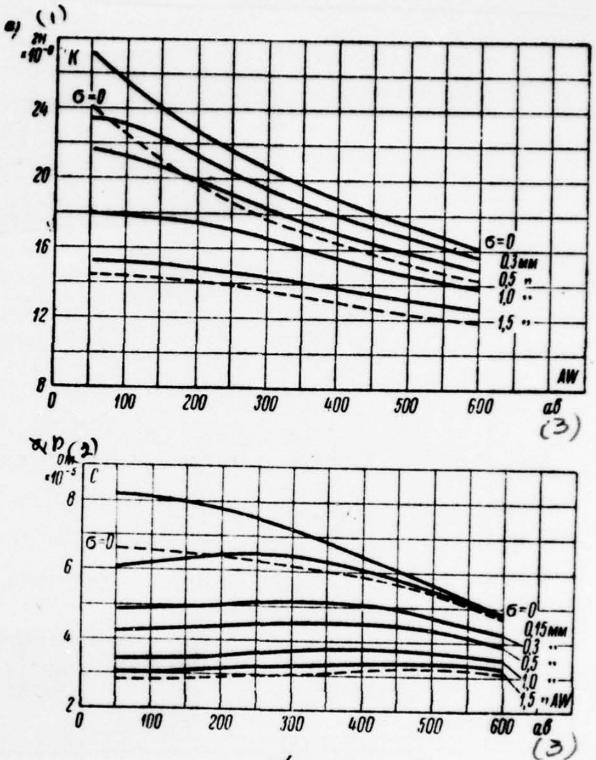

Fig. 20.18.

Fig. 20.17. Curved of dependences u_0 cn ampere turns for relay of type MKU-48.

Key: (1). Volts. (2). AV.

Fig. 20.18. Curved of coefficients K and C for relay of type MKU-48.

Key: (1). H. (2). ohm. (3). AV.

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By relays of the type MKU-48 must reliably work with voltages from 85 to 110o/o of nominal value.

For the calculation of the winding of relay of the type MKU-48 Fig. 20.17 and 20.18 gives the curves of dependences u_0 and of coefficients K and C on ampere turns with different clearances.

As a result of an inaccuracy in the treatment/working and assembly, the reluctance of joints and gaps between core and armature can oscillate within sufficiently large limits; therefore values of coefficients u_0, C and K with the pulled armature (ϵ = 0) can change approximately within the limits, limited by continuous and dotted lines.

For determining the inductance of relay of the type MKU-48 with the constant of current Fig. 20.19 gives the curves of the dependences of coefficient K_0 on ampere-turns.

These some standard relays of direct and alternating current are given in Appendix 1.

20.5. Relays of average power of type RKS-3.

A relay of type RKS-3 is intended for control of the circuits of average power of direct or alternating current (up to 20q) that feed equipment for automation and communication/connection. This relay can be operated at ambient temperatures from -50 to +50°C and relative humidity to 98o/o at temperature of 20°C. Relay maintain/withstands vibration test in the range of frequencies from 25 to 70 Hz during accelerations 4-3 g and impact strength during acceleration 75 g (2000 impacts).

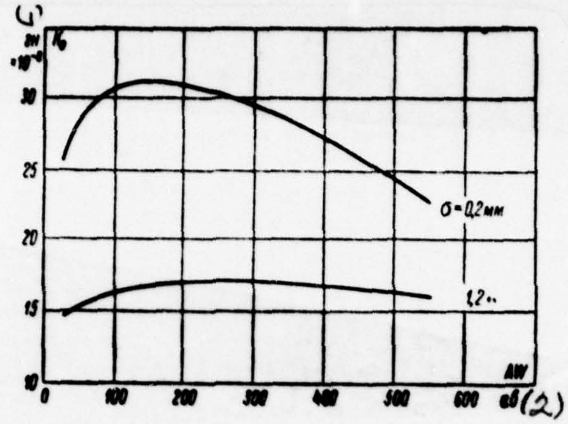

Fig. 20.19. Curved of coefficient $K_{\bullet}$ for relay of type RKU-48.

Key: (1). H. (2). AV.

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For tropical operating conditions, it is manufactured with relay of the type RKS-3T which can work at temperatures from -10 to +55°C and relative humidity to 98o/o at temperature of 35°C.

The general view of this relay is given in Fig. 20.20. The magnetic system of relay of type RKS-3 is assembled from housing, core and the armature of a normal

relay of the type RKN. Core has the pole piece. The front/leading jaw of coil is made of red copper, and rear - out of getinax.

The contact system of relay consists of two motionless collector strips by section 2.5 x 10 mm, strengthened four by screw/propellers on housing in parallel friend and isolate/insulated by thick getinax separators. On each band is fastened of two contacts - fundamental and auxiliary.

Fundamental contact from silver is riveted of the end/lead of the band, it has contact surface as value 5 x 10 mm height 0.8 mm. Auxiliary contact made of tungsten by diameter 4 mm is fastened on band at a distance 27 mm from fundamental contact. During the function of relay, both motionless collector strips are closed between themselves by flexible contact cross connection from band bronze (thickness 0.8 mm), strengthened to the armature of relay.

This cross connection has four springy reeds to which are attached respectively two large linear silver contacts and two circular tungsten contacts. Cross connection is isolate/insulated from armature by getinax separators.

Armature returns to initial position with the flat/plane bronze spring, strengthened to the housing of relay.

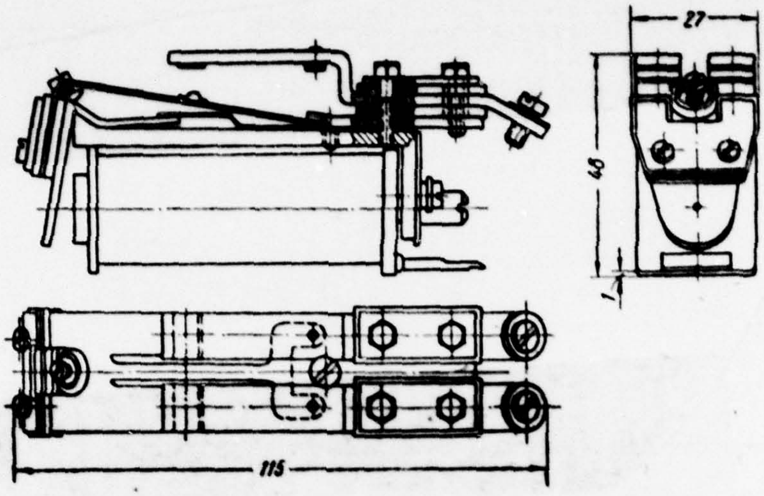

Fig. 20.20. Relays of type RKS-3.

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During the function of relay, first are closed the tungsten contacts, which then are shunted by large silver contacts. With disconnection, on the contrary, first are broken powerful silver contacts without chain cleavage, and then tungsten contacts. Thus, the energy, which is isolated during closing/shorting and interrupting of circuit, is received only by tungsten contacts.

Chain cleavage occurs virtually simultaneously in two

series-connected contacts. Distance between the fundamental contacts 4 mm, between auxiliary 5 mm. Pressure in the fundamental contacts 300-700 g, in auxiliary 50-80 g. Course of armature 5 mm. The maximum value of the current, switched by contacts, 20 A.

The breaking capacity of the contact system of relay of type RKS-3 with direct current 1.0 kW (20 A - 60 volts or 10 A - 110 volts) with alternating current of 2.0 kVA (20 A - 120 volts or 10 A - 220 volts). The testing voltage of insulation of winding 500 volts, of contact system 1500 volts. Service life of the relay of 10^5 cycles.

The winding of relay is supplied by direct current by voltage 24, 48 or 110 volts. Ampere-turns of function 600-650, working ampere turns 800-860.

With the nominal voltage of relay, consumes 2.8-3.0 W. Overall dimensions of relay 27 x 48 x 115 mm, weight 300 g.

20.6. Relays of types RPNV and RPNV-1.

The relays of the direct current of types RPNV and RPNV-1 are intended for the commutation a direct and alternating circuital current of average power with voltage to 250 volts.

Relays are designed for operation in stationary equipment during changes in the ambient temperature from -5 to +40°C and relative humidity to 90o/o (at 20 ±5°C).

The general view of relay of the type RPNV is shown in Fig. 20.21.

In the construction of relay of the type RPNV, are used almost all parts of relay of the type RPN. Core and armature have small structural/design changes. Insulation of winding from core is intensified, it consists of five layers of varnished insulating cloth by thickness 0.10 mm. Winding is saturated with varnish No 447. Equivalent inner diameter of the winding 10.2 mm, height 6.2 mm, length 50 mm. The front/leading jaw of coil has stepped form and it simultaneously serves as support for contact springs.

The contact system of relay of the type RPNV consists of one or two contact groups, assembled into one common packet. Each group can have from one to four contact springs.

Contact springs have approximately the same form as springs of relay RPN.

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The distance between them is increased to 2 mm, spring are isolate/insulated from each other by two separators of getinax by thickness 1 mm. The magnetic system of relay and all fasteners have the intensive anticorrosive coating.

The driving/moving getinax plate of bridge has stepped form. Course of armature 1.5-2.1 mm, the thickness of nonmagnetic antistick strip 0.1 mm. Pressure in the contacts 18-25 g. The gaps among contacts are not less than 0.8 mm. Power, consumed by the winding of relay during function, 0.07-0.3 W. Rated consumption 0.15-0.6 W, capacity - 4.5 W.

Great operating voltage of winding and contacts by 250

volts, the maximum current strength in contacts 1 A. The power, switched by contacts with resistive load and direct current, is 44 W (0.2 A - 220 volts). Service life of the relay of 10^5 cycles. The testing voltage of insulation of winding and contact system 1000 eff. V.

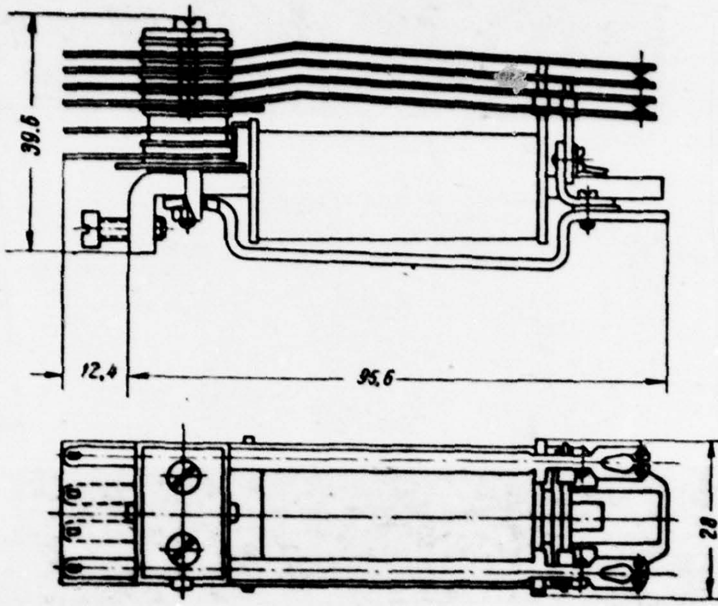

Fig. 20.21. Relays of type RPNV.

Table 20.5. Ampere-turns of the function cf relay of the type RPNV.

Обозначение контактных групп (1)	AW	Обозначение контактных групп (1)	AW
з	112	п — п	139
р	104	рр — рр	186
п	112	з — п	156
з — з	152	зр — п	165
р — р	137		

Key: (1). Designation of contact groups.

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The electrical insulation resistance of relay under normal conditions is more than 500 MΩ, after the stay under conditions of the increased humidity 10 MΩ.

Relay is fastened to board by two screw/propellers. Overall dimensions of relay 28 x 39.6 x 108 mm, weight 220 g.

The ampere-turns of function for a relay of the type RPNV, loaded by different contact groups, are given in Table 20.5.

A relay of type RPNV-1 has a winding, designed to operating voltage to 250 volts, and normal contact systems of relay of the type RPN to operating voltage to 100 volts, contact systems is 500 volts. Overall dimensions of relay 26 x 37.1 x 108 mm, weight 220 g.

20.7. Relays with mechanical interlock of the type REN19.

The relay of direct current with the mechanical retention (blocking) of armature after function of the type REN19, developed by L. A. Dobroserdov, is intended for the commutation of the circuits the direct and alternating current of average power with voltage to 250 volts. The general view of relay is shown in Fig. 20.22.

Relay is designed for operation in fixed systems during changes in the ambient temperature from 0 to +40°C, relative humidity to 98o/o at temperature of 20 ±5°C maintain/withstands vibration test at frequencies from 15 to 70 Hz and upon acceleration 3 g.

A relay of the type REN19 consists cf two relay of the type REN17 whose housings are rigidly connected between themselves two steel plates. One Of these relay is worker, another serves for return to initial position (releases) the first. The end/lead of the armature of working relay is gashed to middle and it is bent back to 90°.

The coils of both relays are shortened on 6.4 mm and

at the projecting end/lead of core of working relay from below is fastened the axis of the lever of locking apparatus. Lever can be turned on the axis and is held in initial position by helical spring.

Growling locking apparatus it has L-shaped form; at one end/lead of the lever, is arrange/located locking tooth for blocking (engaging) the armature of working relay, and on other - projection (backstop), on which presses the armature of the releasing relay during function for the release of the armature of working relay.

During the supplying of short-term current pulse into the winding of working relay, it wear/operates, and its armature mechanically is blocked in the pullled position. For the return of the armature of working relay to initial position, it is necessary to feed current pulse to the winding of the releasing (the second) relay.

The contact system of each relay consists of two groups and can have from 2 to 12 contact springs.

Course of the armature of working relay 2 mm, which releases - 1.7 mm.

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Pressure in the contacts 20-25 g, gaps among contacts are not less than 0.9 mm. Length of the winding of relay 52.7 mm, instead of 59.1 mm of relay of the type REN17.

The ampere-turns of the function of relay of the type REN19, loaded by different contact groups, are given in Table 20.1.

The power, consumed during function by the winding of working relay, depending on load is within the limits from 0.3 to 0.6 W.

In the operating position of relay, does not consume the current, since armature is held by the mechanically locking apparatus.

Great voltage of winding and contacts by 250 volts, the maximum current of contact system 5 A.

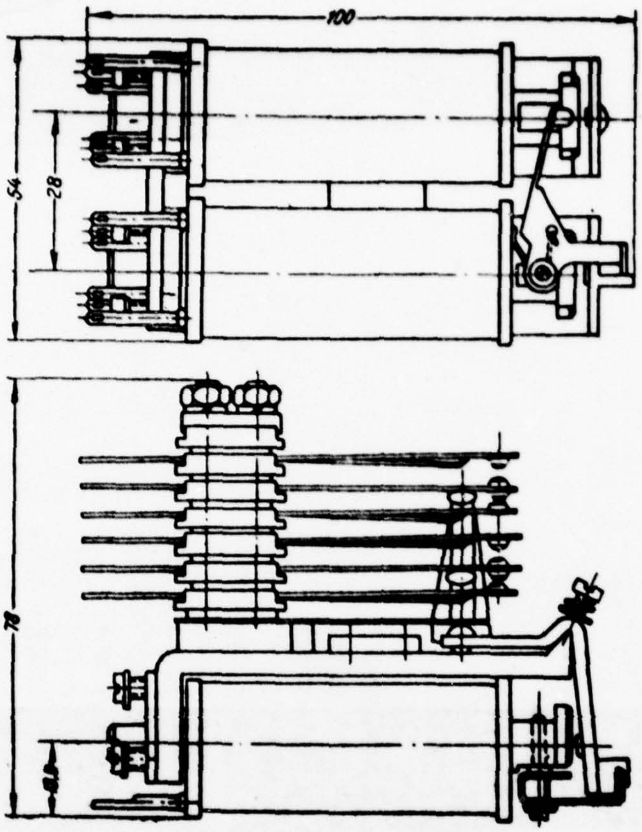

Fig. 20.22. Relays with mechanical interlock of type REN19.

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Power, switched by contacts with non-inductive load and direct current 50 W, with alternating current by frequency 50 Hz - to 500 volt-amperes. Service life of the relay

$1 \cdot 10^5$ of cycles. The testing voltage of insulation of windimg and contacts 1000 volts.

Relay is fastened to board six by screw/propellers. Overall dimensions 54 x 78 x 100 mm, weight 600 g.

20.8. Code relays.

In equipment for automation, fairly often are applied the code relays of direct current, the widespread in warning devices, centralizations and blockings on rail transport [20.1].

Code relays are intended for operation during changes in the ambient temperature from -40 to +60°C and relative humidity to 70o/o. The modification of code relay (relay of the type KDRT) maintain/withstands also operation under conditions of agitation.

Code relays have to 30 different modifications: fundamental relays of the type KDR (KDR1, KDR1-M, KDR2, KDR3, KDR3-M, KDR4, KDR5, KDR6, KDR7, KDR8 and KDR9), relay

with the plug connection/inclusion of the type KDRSh, of the relay for a work under conditions of agitation of the type KDRT, the transmitter relays of the type KTR, of the relay with the large time dilation of release/tempering (to 7.5 s) of the type KMR, relay converter of direct current into the variable of the type KDRP, of the relay, mounted in the individual cases (cells) of types UKDR and UNR and of relay with the magnetic blocking of armature of the type KDRMB.

The modifications of the code relays of the types KDR1s, KDR2s, ..., KDR6s are intended for operation at temperatures from -45 to +60°C, relative humidity to 80o/o and vibration in the range of frequencies from 10 to 70 Hz during acceleration to 3.5 g.

a) fundamental relays.

The general view of relay of the type KRD1 is shown in Fig. 20.23.

The construction of the magnetic system of the relay of types KDR1 and KDR2 is analogous to relay of type RKM-1, but it has considerably larger size/dimensions. The

diameter of the core of the relay of types KDR1 and KDR2 is equal to 12 mm, length its 76 mm. For a decrease in the releasing time, the cores of these (moving rapidly) relays are made of circular silicon steel of brand Section of the housing of relay 3 x 30 mm. Armature is bent made of sheet steel by thickness 2.5 mm. Housing and armature are made made of steel of brand EA. Magnetic circuit is copper-plated and nickel (30 μ). The transmission of the effort/forces of armature to contact groups is realized by getinax plate (shelf), riveted to horn of armature. The length of shelf of relay of the type KDR2 is approximately two times more than in relay of the type KDR1. Armature is held by brass corner iron (lock), strengthened to the housing of relay.

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Coil forms of high-speed relays are manufactured from pressed powder K-21-22, time-lag relay - of red copper. Windings are saturated with insulating varnish.

The contact system of relay of the type KDR1 can have from 1 to 5 contact groups (columns), which contain from 2 to 6 contact springs each. Relays of the type KDR2 are manufactured from one or with two contact springs of aluminum bronze with thickness 0.33-0.4 mm. Width of springs 5.5 mm, length 71-75 mm. The end/leads of contact springs are cut and equipped by two silver contacts by diameter 2.2 mm.

Contact groups are tightened by two screw/propellers, springs are isolate/insulated from each other by separators of plastic K-21-22. Springs are covered with nickel by thickness 2-3 μ. For the elimination of vibration, "motionless" springs are equipped by supporting (spring) springs.

Course of the armature of relay of the type KDR1-2.4 mm, relay of the type KDR2 - 0.6 mm. Height/altitude of the plug of loosening 0.2 mm.

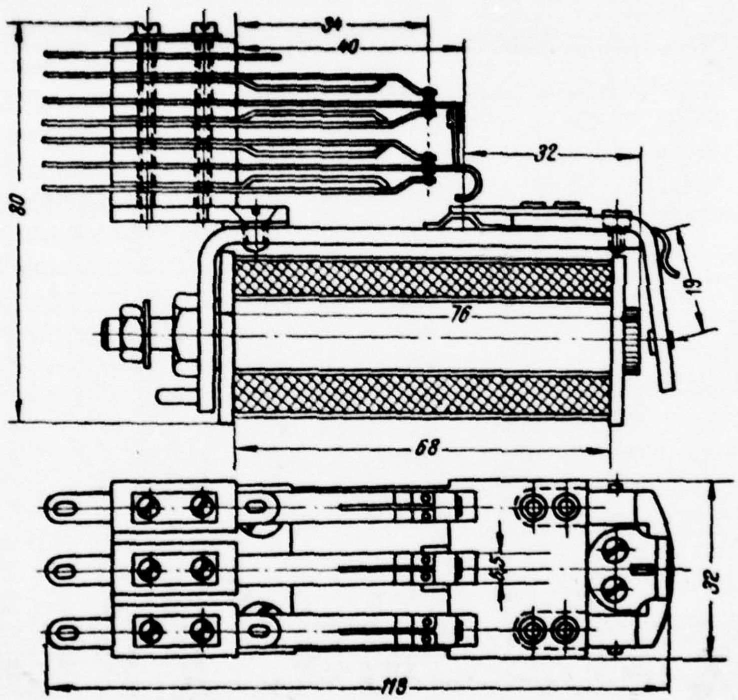

Fig. 20-23. Code relays of type KDR1.

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Pressure in the contacts 25-30 g, the pressure of contact springs on support 8-12 g. Gap between the contacts 0.8-1.2 mm (between the bridge contacts 0.5-1.0 mm).

The power, consumed during the function of relay, depending on the value of the load of armature vibrates

within limits from 0.1 to 1 W. With the nominal voltage of relay, it consumes 0.5-3.0 W. The windings of relay are manufactured to nominal voltages 6, 12, 24, 48, 110 and 220 v.

The certified/rating safety factor on the ampere-turns of function is accepted equal to 1.4, and on the ampere-turns of release/tempering 1.65. The working safety factor on spill current in diagrams must be not below 1.4-1.5.

Greatest permissible continous rating 5.5-6 W (at ϑ = 50°C). The relay reset coefficient of the type KDR1 is 0.2-0.4 relays of the type KDR2 - 0.3-0.6.

The contacts of relay from silver can disrupt current to 2 (KDRT - to 3 A of alternating current with inductive load and voltage 110 V). Relays can long switch the resistive load of direct current by power to 50 W with voltage to 60 V and to 30 W with voltage to 220 v. With inductive load the contacts of relay can switch direct current by power to 50 W with voltage to 24 v, to 30 W with voltage to 60 v and to 20 W with voltage to 220 v. With alternating current by voltage to 220 into the

contacts of relay they can switch the power of 80 volt-amperes.

The service life of the silver contacts of relay 1 million cycles with the smaller period of service the power, switched by contacts, it can be increased. During a decrease in the load of contacts on 50o/c service life of contacts, increase to 5 million countersinks (from subadjustment and by dressing after each million of cycles).

The testing voltage of insulation of winding and contacts is 1000 in alternating current (50 Hz). Electrical insulation resistance under normal conditions is more than 100 MΩ. The overall dimensions of relay cf the type KDR1 is 32 x 75 x 115 mm (with 5 contact groups 54 x 75 x 115 mm), weight 410-470 g.

b) Time-lags relay.

Time-lags relay of types KDR3, KDR4, KDR5, KDR6 and KDR7 have housing of U-shaped form, which encompasses coil from two sides. During the function of relay, the armature

rests not on core, but on the opposite stern of housing. The core of relay of the type KDR3 has a diameter 12 mm, and the relay of types KDR4 - KDR7 - 16 mm.

The relays of types KDR4 KDR6, retarded for function, have quadrature winding from red copper washers, arrange/located in front of coil (of armature).

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The relays of types KDR5 and KDR7 are retarded for release/tempering, quadrature winding (washers) of these relay is arrange/located behind coil (of heel).

The relays of types KDR4-KDR7 have triggering time to 260-350 ms and a releasing time 650-1000 ms.

Overall dimensions of these relays 34 (54) x 85 x 140 mm, weight 950-1000 g.

Transmitter relays of the type KTR are characterized by from relay of the type KDR the presence of one or two contact groups of the increased power with cermet contacts instead of the silver.

c) Relays with large retarding/deceleration/delay.

Relay with the large time dilation of release/tempering (to 5 s) of the type DMR1 (SR2) has also housing of U-shaped form, but it is makcharacterized by the large size/dimensions and the presence of the pole piece. The general view of relay MR1 is shown in Fig. 20-24. The cores of the relay of types MR1 - MR6 have diameter 25 mm, the pole piece - 40 mm. Section of housing 6 x 55 mm. Length of the winding 26 mm. Length of red copper plug 70 mm, outside diameter its 53 mm.

The contact system of relay consists of two contact groups with circuit closing contacts. Between contacts is arrange/located flat spring with the adjusting screw, which makes it possible to regulate the time of release of relay by changing the pressure of spring on armature. The contacts of relay of the type KMR1 have a diameter 4.5 mm and are made from the composition of brand SrKd86-13 (silver 86o/o and cadmium 14o/o). Period of service of

these contacts 2 million cycles with load indicated above. Course of the armature of relay 1.2 mm, the remanent/residual gap between armature and core 0.15 mm. Pressure in the contacts 20-30 g, the gap between them 1.5 mm.

The great time dilation of release/tempering has relay of the type KMR3 (VR) (7-8 s); the remanent/residual gap between armature and core is equal to 0.05 mm.

A relay of the type KMR3 has two windings, upon contrary connection/inclusion through 2000 ohm of the second winding simultaneously with the disconnection of fundamental - the releasing time of relay decreases to 3-3.5 s.

The relays of types KMR4 (SR-1GATs) and KMR5 (SR-2GATs) are characterized by from relay KMR1 the reduced length of plug for obtaining the large retarding/deceleration/delays by release/tempering during pulsed mode.

Relay KMR6 (KSR) has one closing and one breaking contact instead of two closing in relay KMR1-KMR5.

The power, consumed with the nominal voltage of relay

of the type KMR1 composes 7.6 W, relay of the type KMR3 and KMR6 - 3.8-4.2 W, a relay of the type KMR2 - 1.75 W. Triggering times and release/tempering of relay of the type KMR are given in table 20-6.

The time characteristics of relay can differ from the nominal value to ±25o/o at temperature of +20°C.

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The first values of triggering times and release/tempering, given in this table, are related to the smallest load of armature (two springs), but the second values - to the full load of armature for this type of relay. The overall dimensions of relay of the type KMR is 55 x 104 x 145 mm, weight of approximately 3100 g.

d) High-speed relays.

The relays of types KDR8 (A) and KDR9 (4DKL) are the high-speed relays of the increased sensitivity. These relays have a core as diameter 10 mm with the pole piece by diameter 25 mm. A relay of the type KDR8 has one stud

switch, while relay of the type KDR9 are not more than three contact groups. The power of the function of relay of the type KDR8 is 0.037 W, and relay of the type KDR9-0.09 W. The overall dimensions of relay of the type KDR8 is 32 x 62 x 139 mm, weight 625 g.

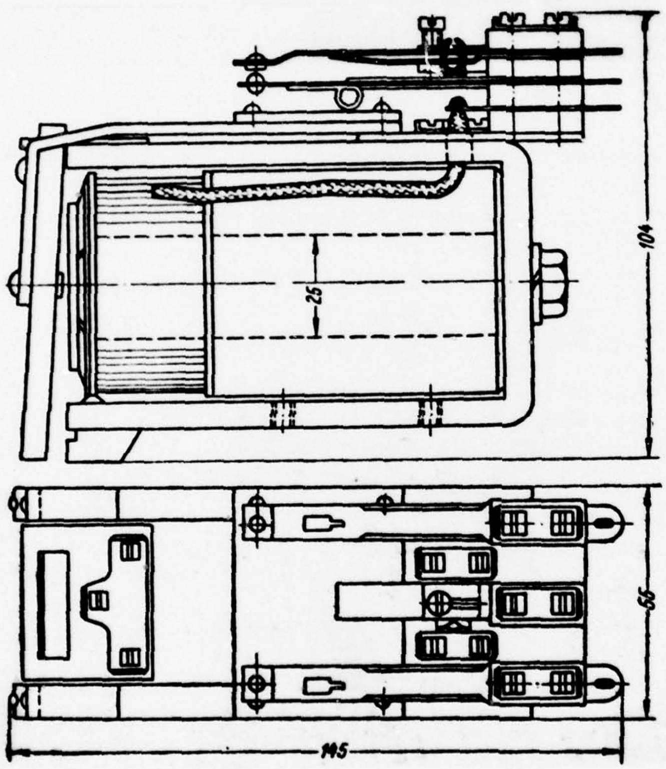

Fig. 20-24. Relays with large time dilaticn of release/tempering of type KMR1.

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d) Relays with blocking.

Relay with magnetic blocking type KDRMB is relay of the type KDR1 whose core is made of silicide magnet steel of brand YeKh2 or carbonic.

After the disconnection of fundamental armature winding, of relay is held in the pulled position because of the large cohesive force of core. For the unlocking (release/tempering) of relay, it is necessary to feed to fundamental or supplementary winding the countercurrent of the specific value.

A deficiency/lack in this relay consists in the fact that the countercurrent must not exceed the spill current of relay in order to avoid the repeated function of relay immediately after its release/tempering due to the magnetic reversal of core.

With a random short-term increase of the circuital current of opening winding of relay, it can be blocked for a second time. Therefore relay with magnetic blocking one should manufacture not from of consecutive, but with bridge or differential circuit magnetic circuit. A relay of the type KDRMB has load to 4-5 stud switches. Required power 4-7 W (working ampere-turns 1000-1200.

Table 20-6. Triggering time and release/tempering of the relay of types KDR and SR.

(1) Тип реле	(2) Наибольшее количество контактных пружин	(3) Мощность срабатывания P_c, *вт*	(4) Номинальная мощность $P_н$, *вт*	(5) Время срабатывания t_c, *мсек*	(6) Время отпускания $t_{от}$, *мсек*	(7) Время отпускания при импульсном режиме $t_{оп}$ *мсек*,	(8) Длительность импульса $t_{имп}$, *мсек*
КДР1	30	1,0	3,9	15—120	15—2	—	—
КДР1-М	18	1,0	—	15—120	85—7	—	—
КДР2	12	0,88	—	14—100	10—1	—	—
КДР3-М	30	—	3,4	18—130	260—70	—	—
КДР4	30	—	—	80—350	650—150	—	—
КДР5	30	—	3,0	15—260	650—150	—	—
КДР6	30	—	4,0	80—350	1000—240	—	—
КДР7	30	—	—	15—260	1000—240	—	—
СР1 (КМР1)	4 (2з)	0,11	7,6	50	5000	1500	200
СР2 (КМР2)	4 »	0,44	1,75	50	2500	—	—
ВР (КМР3)	4 »	0,22	3,76	50	7500	—	—
СР1-ГАЦ (КМР4)	4 »	0,45	7,2	50	2700	1500	100
СР2-ГАЦ (КМР5)	4 »	0,77	14,4	50	2700	1300	100
КСР (КМР6)	4 (1з+1р)	0,10	4,17	50	5000	—	—

Key: (1). Type of relay. (2). Great quantity of contact springs. (3). Power of function W. (4). Nominal power W. (5). Triggering time ms. (6). Releasing time ms. (7). Releasing time during pulsed operation ms. (8). Duration of momentum/impulse/pulse ms.

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Appendix 1.

Table specifications some standard relays.

(1) Тип реле	(2) Контактные группы	(3) Номинальное напряжение или ток	(4) Сопротивление, ом	(5) Число витков	(6) Диаметр проволоки, мм	(7) Ток или напряжение срабатывания	(8) Ток отпускания, ма
РЭС8	ппп—ппп	24 в (9)	160	2 700	0,14	86 ма	—
РЭС8	ппп—ппп	27 в (9)	180	2 900	0,14	80 ма	—
РЭС8	ппп—ппп	110 в (9)	2100	8 300	0,07	28 ма (10)	—
РЭС8	ппп—ппп	23 ма	3500	11 000	0,06	20 ма	—
РЭС8	ппп—ппп	17 ма (10)	8000	17 000	0,05	13 ма	—
РЭС9	п—п	6 ± 1 в (9)	30	1 400	0,13	108 ма	18
РЭС9	п—п	> 10 в (9)	72	1 800	0,10	80 ма (10)	13
РЭС9	п—п	23—32 в	500	4 600	0,06	30 ма	5
РЭС9	п—п	> 13,5 ма (10)	3400	13 000	0,04	11 ма	1,7
РЭС9	п—п	> 8,3 ма	9600	21 000	0,03	7 ма	1,1
РЭС10	п	5,5 в	45	1 100	0,10	80 ма	—
РЭС10	п	9,0 в (9)	128	1 800	0,08	50 ма	—
РЭС10	п	24 в	630	4 000	0,05	22 ма	—
РЭС10	з (11)	12 ма	1600	6 500	0,04	9,5 ма (10)	—
РЭС10	п	9,5 ма (10)	4500	11 000	0,03	8 ма	—
РЭС10	з (11)	7 ма	4500	11 000	0,03	6 ма	—
РЭС15	п	73—85 ма	36	890	0,10	60 ма	14
РЭС15	п	39—46 ма (10)	160	1 700	0,06	30 ма	7
РЭС15	п	27—33 ма	330	2 000	0,05	21 ма (10)	5
РЭС15	п	19—22 ма	720	3 500	0,04	14,5 ма	3,5
РЭС15	п	11—13 ма	2200	6 000	0,03	8,5 ма	2
РЭС22	пп—пп	12 в (9) ± 10%	175	3 400	0,10	36 ма	8
РЭС22	пп—пп	24 в ± 10%	650	6 200	0,07	20 ма	4
РЭС22	пп—пп	30 в ± 10%	700	6 300	0,07	21 ма	3
РЭС22	пп—пп	48 в ± 10%	2500	11 500	0,05	10,5 ма (10)	2,5
РЭС22	пп—пп	60 в ± 10%	2800	11 500	0,05	9 ма	2
РДЧГ	п	—	130	6 000	0,17	8 ма (10)	—
РДЧГ	п	—	2100	22 000	0,08	2 ма	0,6
РКМП	пп	—	100	4 250	0,21	36 ма	—
РКМП	ппп—ппп	—	400	8 500	0,15	25 ма	—
РКМП	з—з (11a)	—	1700	16 350	0,10	7,5 ма (10)	—
РКМП	з (11)	—	4000	25 000	0,08	4,5 ма	—

Key: (1). Type of relay. (2). Contact group. (3). Nominal voltage or current. (4). Resistor/resistance, ohm. (5). Turn number. (6). Diameter of wire, mm. (7). Current or the actuation voltage. (8). It flowed release/tempering, mA. (9). v. (10). mA. (11). z. (11a). Z-Z. (12). Failure. (13). b.

1 Тип реле	2 Контактные группы	3 Номинальное напряжение или ток	4 Сопротивление, *ом*	5 Число витков	6 Диаметр проволоки, *мм*	7 Ток или напряжение срабатывания	8 Ток отпускания, *ма*
РСЧ-52	*пп—пп*	24 *в* (9)	220	4 500	0,14	60 *ма*	—
РСЧ-52	*п—п*	—	420	6 250	0,11	34 *ма* (10)	—
РСЧ-52	*ппп—ппп*	—	9000	28 000	0,05	13 *ма*	2,9
РСЧ-52	*з—р*	—	9000	26 000	0,05	8,5 *ма*	—
РС-13	*ппп—ппп*	24 *в* (9)	250	5 400	0,13	80 *ма*	15
РС-13	*п—п*	24 *в*	400	6 250	0,11	37 *ма* (10)	7
РС-13	*з—пп*	—	8000	28 000	0,05	10 *ма*	2,5
РС-13	*з* (11)	—	8000	28 000	0,05	7,0 *ма*	—
РМУ	*пп—пп*	27 *в*	430	6 150	0,11	38 *ма*	8,5
РМУ	*пз—п*	27 *в*	680	8 000	0,10	23 *ма*	5,0
РМУ	*пз—пз* (11)	60 *в* (9)	3200	17 000	0,07	12 *ма* (10)	—
РМУ	*з*	60 *в*	5000	20 000	0,06	8 *ма*	—
РМУ	*п—п*	60 *в*	5600	22 000	0,06	8 *ма*	1,5
РЭС6	*п—п*	—	300	4 300	0,09	50 *ма*	10
РЭС6	*п—п* (11)	24 *в* (9)	550	6 200	0,08	35 *ма*	8
РЭС6	*з—з*	27 *в*	850	6 600	0,07	25 *ма* (10)	5
РЭС6	*р—р*	—	1250	8 500	0,06	21 *ма*	4
РЭС6	*п*	—	2500	12 000	0,05	15 *ма*	3
РСМ-1	*з—з*	—	750	5 000	0,06	25 *ма*	5,0
РСМ-2	*з—р*	—	525	4 500	0,07	26 *ма*	4,5
РСМ-1	*з—з* (11)	—	250	3 000	0,08	40 *ма* (10)	—
РСМ-1	*з—з*	—	200	2 800	0,09	45 *ма*	8,0
РСМ-3	*р—р*	—	120	2 100	0,10	70 *ма*	—
РП-3	*п*	—	*I* 130	1 250	0,09	2,4—6,4 *ма* (10)	—
		—	*II* 130	1 250	0,09	2,4—6,4 *ма*	—
РП-4	*п*	—	*I* 4,5	500	0,27	2—8 *ма* (10)	—
		—	*II* 300	5 000	0,14	0,2—0,8 *ма*	—
РП-4	*п*	—	*I* 290	2 500	0,09	0,4—1,6 *ма* (10)	—
		—	*II* 290	2 500	0,09	0,4—1,6 *ма*	—
РП-4	*п*	—	*I* 8500	22 000	0,05	0,045—0,18 *ма* (10)	—
		—	*II* 8500	22 000	0,05	0,045—0,18 *ма*	—
РП-5	*п*	—	*I* 55	1 000	0,1	1—4 *ма* (10)	—
РП-5	*п*	—	*I* 1200	12 000	0,1	0,083—0,33 *ма* (10)	—
РПБ-5	*п*	—	*I* 4800	17 000	0,06	0,058—0,24 *ма* (10)	—
		—	*II* 4800	17 000	0,06	0,058—0,24 *ма*	—
РП-5	*п*	—	*I* 9500	34 000	0,06	0,029—0,12 *ма* (10)	—
РП-7	*п*	—	*I* 1,5	320	0,44	12,5—31,2 *ма* (10)	3,8—15,6
		—	*II* 1,5	320	0,44	12,5—31,2 *ма*	3,8—15,6

1 Тип реле	2 Контактные группы	3 Номинальное напряжение или ток	4 Сопротивление, ом	5 Число витков	6 Диаметр проволоки, мм	7 Ток или напряжение срабатывания	8 Ток отпускания, ма
РП-7	п	—	*I* 6300	25 500	0,06	0,153—0,38 ма	0,047—0,196
РПС-5	п	— —	*I* 1500 *II* 1500	11 200 11 200	0,07 0,07	0,09—0,27 ма 0,09—0,27 ма	— —
РПС-5	п	— —	*I* 6500 *II* 6500	23 000 23 000	0,05 0,05	0,044—0,13 ма 0,044—0,13 ма	— —
РПС-7	п	— —	*I* 6500 *II* 6500	23 000 23 000	0,05 0,05	0,17—0,43 ма 0,17—0,43 ма	0,07—0,18 0,07—0,18
РПС-7	п	— —	*I* 8000 *II* 2700	34 000 8 000	0,05 0,05	0,12—0,3 ма 0,5 —1,25 ма	0,047—0,12 0,2—0,5
РПС-11/3	п	— — — —	*I* 120 *II* 120 *III* 120 *IV* 120	1250 1250 1250 1250	0,09 0,09 0,09 0,09	2,4—4,8 ма 2,4—4,8 ма 2,4—4,8 ма 2,4—4,8 ма	— — — —
РПС-11/4	п	— — — —	*I* 120 *II* 120 *III* 120 *IV* 120	1250 1250 1250 1250	0,09 0,09 0,09 0,09	0,8—3,2 ма 0,8—3,2 ма 0,8—3,2 ма 0,8—3,2 ма	— — — —
РПС-11/5	п	— —	*I* 4000 *II* 4000	14 000 14 000	0,05 0,05	0,072—0,285 ма 0,072—0,285 ма	— —
РПС-11/7	п	— —	*I* 4000 *II* 4000	14 000 14 000	0,05 0,05	0,286—0,72 ма 0,286—0,72 ма	0,086—0,356 0,086—0,356
РПС-18/4	п	— —	*I* 275 *II* 275	3500 3500	0,09 0,09	0,8—2,8 ма 0,8—2,8 ма	— —
РПС-18/4	п	— —	*I* 2500 *II* 2500	10 000 10 000	0,05 0,05	0,3—1,5 ма 0,3—1,5 ма	— —
РПС-18/5	п	—	*I* 6	820	0,29	< 16,5 ма	—
РПС-18/5	ч	— —	*I* 2500 *II* 2500	10 000 10 000	0,05 0,05	< 1,5 ма < 1,5 ма	— —
РПС-18/7	п	— —	*I* 275 *II* 275	3500 3500	0,09 0,09	1—4 ма 1—4 ма	0,2—0,8 0,2—0,8
РПС-18/7	п	— —	*I* 2500 *II* 2500	10 000 10 000	0,05 0,05	0,3—1,5 ма 0,3—1,5 ма	0,1—0,5 0,1—0,5
РПС-18/7	п	— — —	*I* 12 000 *II* 12 000 *III* 4 500	20 000 20 000 5 000	0,03 0,03 0,03	0,6—0,9 ма 0,6—0,9 ма 2,4—3,6 ма	0,2—0,4 0,2—0,4 0,8—1,6

(1) Тип реле	(2) Контактные группы	(3) Номинальное напряжение или ток	(4) Сопротивление, ом	(5) Число витков	(6) Диаметр проволоки, мм	(7) Ток или напряжение срабатывания	(8) Ток отпускания, ма
РПС-20	п—п	5,4 в (9)	I 30 II 30	1000 1000	0,12 0,12	3,6 в 3,6 в (9)	(10) Несрабатывание 1,8 в 1,8 в (9)
РПС-20	п—п	10,8 в (9)	I 130 II 130	2000 2000	0,08 0,08	7,8 в 7,8 в (9)	3,9 в 3,9 в (9)
РПС-20	п—п	14,4 в (9)	I 200 II 200	2400 2400	0,07 0,07	10 в 10 в (9)	5,0 в 5,0 в (9)
РПС-20	п—п	24 в (9)	I 660 II 660	4000 4000	0,05 0,05	18 в 18 в (9)	8,0 в 8,0 в (9)
ДП-12	ппп— —ппп— —ппп— —ппп	24 в 24 в 24 в (9) 24 в	I 300 II 300 III 300 IV 300	4000 4000 4000 4000	0,10 0,10 0,10 0,10	18 в 18 в (9) 18 в 18 в	10 в 10 в (9) 10 в 10 в
РПН РПН РПН РПН РПН РПН РПН	и—и—и —г— аа—аа—аа аг—аг гг—гг а а	— — — — — — —	250 600 1 000 2 000 3 000 5 000 15 000	6 900 10 000 13 500 18 900 22 900 30 000 49 000	0,17 0,13 0,12 0,10 0,09 0,08 0,06	22 ма 8 ма 12 ма (10) 7 ма 7 ма 3 ма 1,8 ма	— — — — — — —
РКН РКН РКН РКН РКН РКН РКН РКН РКН РКН	9—2 5—1 3—3 5—5 35—35 5—1 4—4 2—1 —3 —1	— — — — — — — — — —	100 250 400 600 800 1 200 2 000 5 000 10 000 18 000	5 000 8 100 10 000 12 300 14 300 17 500 20 000 31 000 45 000 60 000	0,23 0,19 0,16 0,15 0,14 0,13 0,10 0,08 0,07 0,06	34 ма 16 ма 11 ма 12 ма 14 ма (10) 6,5 ма 7,0 ма 5,0 ма 2,0 ма 1,3 ма	— — — — — — — — — —
РКМ-1 РКМ-1 РКМ-1 РКМ-1 РКМ-1	и—г—и аи—аи —и— и—и—и —а—	— — — — —	250 500 1300 3300 6000 6000	6 400 9 200 13 900 21 000 28 300 28 300	0,14 0,11 0,09 0,07 0,06 0,06	34 ма 21 ма 8,0 ма (10) 6,0 ма 4,5 ма 3,5 ма	— 5 — — — —
РПНВ РПНВ РПНВ РПНВ	п п—п ер—ер ее—ее	— — — —	800 2 500 6 300 19 000	7 000 18 000 30 000 50 000	0,11 0,09 0,07 0,05	1 ма 9 ма (10) 7 ма 3,8 ма	— — — —

(1) Тип реле	(2) Контактные группы	(3) Номинальное напряжение или ток	(4) Сопротивление, ом	(5) Число витков	(6) Диаметр проволоки, мм	(7) Ток или напряжение срабатывания	(8) Ток отпускания, ма
РЭН17	пз—пз	24 в	200	7 100	0,20	45 ма	—
РЭН17	пз—пз	24 в	500	11 200	0,16	28 ма	—
РЭН17	п—п	36 в	1 000	12 600	0,11	20 ма	—
РЭН17	р—р	36 в	1 400	18 000	0,12	14 ма	—
РЭН17	з—з	36 в	2 600	23 500	0,10	8 ма	—
РЭН17	пз—пз	110 в	10 000	63 500	0,07	7,5 ма	—
РЭН18	пз—пз	12 в	100	5 100	0,25	65 ма	—
РЭН18	ззз—ззз	24 в	300	8 000	0,17	50 ма	—
РЭН18	з—з	24 в	1000	14 700	0,13	19 ма	—
РЭН19	(п—п (Р)	12 в	700	12 300	0,14	19 ма	—
	((Б)	12 в	300	8 000	0,17	40 ма	—
РЭН19	(п—п (Р)	24 в	1000	14 800	0,13	16 ма	—
	((Б)	24 в	1000	14 800	0,13	22 ма	—
РЭН19	(пп—п (Р)	60 в	4000	28 000	0,09	12 ма	—
	(з (Б)	60 в	1900	20 000	0,11	21 ма	—
РЭН19	(пп—п (Р)	60 в	2600	23 000	0,10	13 ма	—
	(п (Б)	60 в	2600	23 000	0,10	17 ма	—
РЭН20	п—п	24 в	13	1 200	0,35	18 в	—
РЭН20	пп—пп	127 в	500	7 000	0,14	100 в	—
РЭН20	пп—пп	220 в	1300	11 000	0,11	170 в	—
РЭН21	зр—р	90 в	440	6 500	0,13	—	—
РЭН21	п—п	220 в	2800	14 500	0,08	—	—
РЭН21	р—р	220 в	4000	17 000	0,07	—	—
РЭН21	зр—рр	220 в	5600	20 000	0,06	—	—
МКУ-48 постоянного тока	з—з	24 в	1 200	8 000	0,11	16 ма	—
	п—п	110 в	6 000	17 000	0,07	12 ма	—
то же	пр—пр	220 в	20 000	27 000	0,05	14 ма	—
МКУ-48 переменного тока	зр—зр	127 в	900	7 000	0,12	38 ма	—
	з—з	127 в	1 100	7 500	0,11	25 ма	—
то же	пз—пз	220 в	2 700	12 000	0,09	23 ма	—
то же	зр—зр	380 в	12 000	23 000	0,06	12 ма	—
РКС-3	з	24 в	200	7 200	0,20	85 ма	—
РКС-3	з	48 в	800	14 800	0,14	45 ма	—
РКС-3	з	110 в	4000	29 700	0,09	22 ма	—

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APPENDIX 2

International system of ones (SI).

(1) Величина	(2) Буквенные обозначения	(3) Наименование	(4) Размерность	(5) Обозначение	(6) Содержит единиц нерационализированной системы СГСМ
		(7) 1. Основные единицы			
Длина (8)	l	Метр (9)	м	м	10^2 (см) (10)
Масса (11)	m	Килограмм (12)	кг (13)	кг (13)	10^3 (г) (14)
Время (15)	t	Секунда (16)	сек (17)	сек (17)	1 (сек) (17)
Ток (18)	I	Ампер (19)	а	а	10^{-1}
		(100) 2. Механические единицы			
Скорость (20)	v	Метр в секунду (21)	м/сек (22)	м/сек (22)	10^2 (см/сек) (23)
Ускорение (24)	a	Метр в секунду за секунду (25)	м/сек² (22)	м/сек² (22)	10 (см/сек²) (23)
Энергия, работа (26)	W, A	Джоуль или ватт-секунда (27)	$\frac{\text{кГ}\cdot\text{м}^2}{\text{сек}^2}=\text{дж}$ (28)	дж (29)	10^7 (эрг) (30)
Сила (31)	F	Ньютон (32)	$\frac{\text{кГ}\cdot\text{м}}{\text{сек}^2}=\frac{\text{дж}}{\text{м}}$ (33)	н (34)	10^5 (дин) (35)
Мощность (36)	P	Ватт (37)	$\frac{\text{кГ}\cdot\text{м}^2}{\text{сек}^3}=\frac{\text{дж}}{\text{сек}}$ (38)	вт (39)	10^7 (эрг/сек) (40)
		(41) 3. Электрические единицы			
Напряжение (42)	U	Вольт (43)	$\frac{\text{кГ}\cdot\text{м}^2}{\text{а}\cdot\text{сек}^3}=\text{в}$ (44)	в (45)	10^8
Количество электричества (46)	q	Кулон (47)	$\text{а}\cdot\text{сек}=\text{к}$ (48)	к (49)	10^{-1}
Электрическая емкость (50)	$C_и$	Фарада (51)	$\frac{\text{а}^2\cdot\text{сек}^4}{\text{кГ}\cdot\text{м}^2}=\frac{\text{а}\cdot\text{сек}}{\text{в}}$ (52)	ф (53)	10^{-9}
Электрическая постоянная (54)	ε_0	Фарада на метр (55)	$\frac{\text{а}\cdot\text{сек}^4}{\text{кГ}\cdot\text{м}^3}$ (56)	ф/м (57)	$4\pi\cdot10^{-11}$
Сопротивление (58)	r	Ом (59)	$\frac{\text{кГ}\cdot\text{м}^2}{\text{а}^2\cdot\text{сек}^3}=\frac{\text{в}}{\text{а}}$ (60)	ом (61)	10^9
Удельное сопротивление (62)	ρ	Ом-метр (63)	$\frac{\text{кГ}\cdot\text{м}^3}{\text{а}^2\cdot\text{сек}^3}$ (64)	ом·м (65)	10^{11}
Удельная проводимость (66)	γ	Сименс на метр (67)		$\frac{\text{сим}}{\text{м}}$ (68)	10^{-11}
		(69) 4. Магнитные единицы			
Магнитный поток (70)	Φ	Вебер (71)	$\frac{\text{кГ}\cdot\text{м}^2}{\text{а}\cdot\text{сек}^2}=\text{в}\cdot\text{сек}$ (72)	вб (73)	10^8 (максвелл) (74)
Магнитная индукция (75)	B	Тесла (76)	$\frac{\text{кГ}}{\text{а}\cdot\text{сек}^2}=\frac{\text{в}\cdot\text{сек}}{\text{м}^2}$ (77)	тл (78)	10^4 (гаусс) (79)
Напряженность магнитного поля (80)	H	Ампер на метр (81)	$\frac{\text{а}}{\text{м}}$ или $\frac{\text{ав}}{\text{м}}$ (82)	$\frac{\text{а}}{\text{м}}$ или $\frac{\text{ав}}{\text{м}}$ (82)	$4\pi\cdot10^{-3}$ (эрстед) (83)
Индуктивность (84)	L	Генри (85)	$\frac{\text{кГ}\cdot\text{м}^2}{\text{а}^2\cdot\text{сек}^2}=\frac{\text{в}\cdot\text{сек}}{\text{а}}$ (86)	гн (87)	10^9 (см) (10)
Магнитодвижущая сила (88)	M	Ампер или ампер-виток (89)	а или ав (90)	а или ав (91)	$4\pi\cdot10^{-1}$ (гильберт) (92)
Магнитное сопротивление (93)	$R_м$	Ампер на вебер (94)	$\frac{\text{а}^2\cdot\text{сек}^2}{\text{кГ}\cdot\text{м}^2}$ (95)	а/вб (96)	$4\pi\cdot10^{-9}\left(\frac{1}{\text{см}}\right)$ (97)
Магнитная проводимость (98)	G	Вебер на ампер (99)	вб/а (100)	вб/а (100)	$\frac{1}{4\pi}10^9$ (см) (101)
Магнитная постоянная (102)	μ_0	Генри на метр (103)	$\frac{\text{кГ}\cdot\text{м}}{\text{а}^2\cdot\text{сек}^2}=\frac{\text{в}\cdot\text{сек}}{\text{м}^2}\cdot\frac{\text{м}}{\text{а}}$ (104)	гн/м (105)	$\frac{1}{4\pi}10^7$

Note. One Newton in system of practical units kg•cm•s

is equal to 0.102 kgf.

Key: (1). Value. (2). Letterings. (3). Designation. (4). Dimensionality. (5). Designation. (6). It contains the systems of the nonrationalized unit kgcm. (7). Fundamental units. (8). Length. (9). Meter. (10). cm. (11). Mass. (12). Kilogram. (13). kg. (14). g. (15). Time. (16). Second. (17). s. (18). Current. (19). Ampere. (19a). Mechanical units. (20). Speed. (21). Meter into seconds. (22). m/s. (23). cm/s. (24). Acceleration. (25). Meter per second for second. (26). Energy, work. (27). Joule or wattsecond. (28). $kg \bullet m^2/s^2$ = J. (29). J. (30). erg. (31). force. (32). Newton. (33). $kg \bullet m/s^2$ = J/m. (34). n. (35). dynes. (36). Power. (37). Watt. (38). $kg \bullet m^2/s^3$ = J/s. (39). W. (40). erg/s. (41). Electrical ones. (42). Voltage. (43). Volts. (44). $kg \bullet m^2/A \bullet s$ = v. (45). v. (46). Quantity of electricity. (47). Coulomb. (48). $A \bullet s$ = k. (49). k. (50). Electrical capacitance. (51). Farad. (52). $A^2 \bullet s^4/kg \bullet m^2$ = $A \bullet s/V$. (53). f. (54). Electrical constant. (55). Farad per meter. (56). $A \bullet s^4/kg \bullet m$: pd^3. (57). F/m. (58). Resistor/resistance. (59). Ohm. (60). $kg \bullet m^2/A^2 \bullet s^3$ = V/A. (61). ohm. (62). Specific resistor/resistance. (63). ohmmeter. (64). $kg \bullet m^3/A^2 \bullet s^3$. (65). (66). Specific conductivity. (67). Siemens to meter. (68). S/m. (69). Magnetic units. (70).

Magnetic flux. (71). Weber. (72). $kg \cdot m^2/A \cdot s^2$ = $V \cdot s$. (73). Wb. (74). Maxwell. (75). Magnetic induction. (76). T. (77). $kg/A \cdot s^2$ = $V \cdot s/m^2$. (78). ml. (79). gauss. (80). Magnetic intensity. (81). Ampere to meter. (82). A/m or AV/m. (83). oersted. (84). Inductance. (85). Henry. (86). $kg \cdot m^2/A^2 \cdot s^2$ = $V \cdot s/A$. (87). H. (88). magnetomotive force. (89). Ampere or magnetic turn. (90). and or AB. (91). and or AB. (92). Gilbert. (93). Reluctance. (94). Ampere to weber. (95). $A^2 \cdot s^2/kg \cdot m^2$. (96). A/ab. (97). cm. (98). Magnetic conductivity. (99). Weber to ampere. (100). vb/A. (101). $1/4\pi\ 10^9$ (cm). (102). Magnetic constant. (103). Henry to meter. (104). $kg \cdot m/A^2 \cdot s^2$ = $V \cdot s/m^2 \cdot m/A$. (105). H/m.

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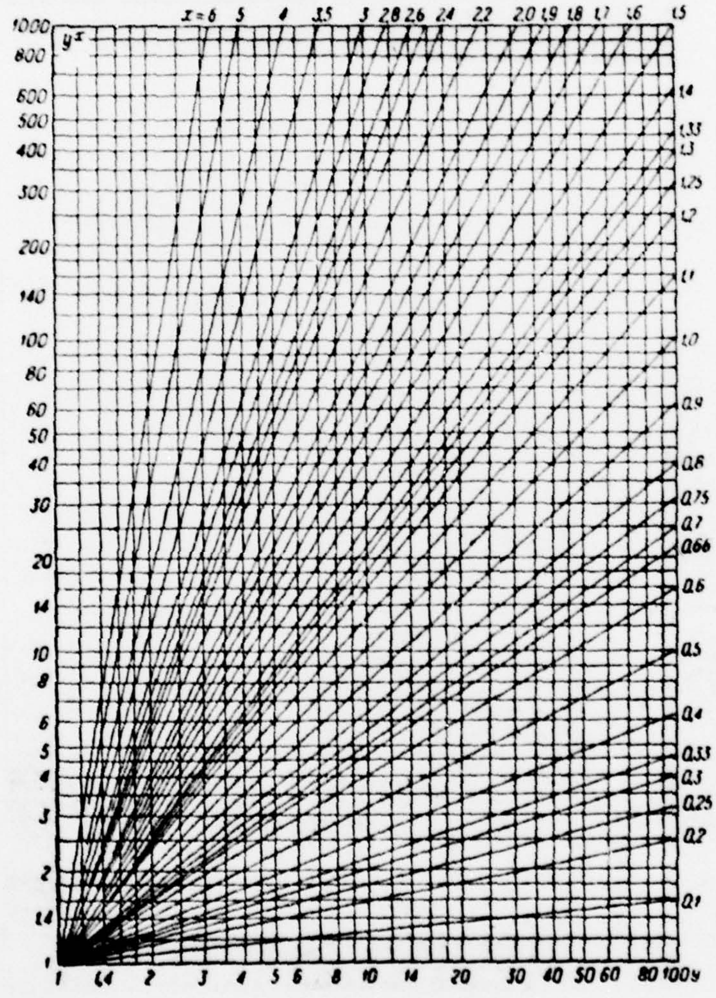
Appendix 3.

Curved of values y^x.



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